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Emission Factors for Iron and Steel Sources Criteria and Toxic Pollutants

Pechan (E.H.) and Associates, Inc., Durham, NC

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EMISSION FACTORS FOR IRON AND STEEL SOURCES - CRITERIA AND TOXIC POLLUTANTS

by

William R. Barnard

E.H. Pechan and Associates, Inc.
3514 University Drive
Durham, North Carolina 27707

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EPA Project Officer:

Robert C. McCrillis

Air and Energy Engineering Research Laboratory
Research Triangle Park, North Carolina 27711

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ABSTRACT

This study provides a comprehensive set of emission factors for sources of both criteria and toxic air pollutants in integrated iron and steel plants and specialty electric arc shops (mini-mills). Emission factors are identified for process sources, process fugitive and open source fugitive emissions. The emission factors are not specific to any one facility. Emission factors for gray iron foundries and the ferroalloy industry are not included.

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Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

Air and Energy Engineering Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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U.S. Environmental Protection Agency
Cincinnati, OH 45268

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EXECUTIVE SUMMARY

The objective of this study is to provide a comprehensive set of emission factors for sources of both criteria and toxic air pollutants in integrated iron and steel plants and specialty electric arc shops (mini-mills). Emission factors are identified for process sources, process fugitive and open source fugitive emissions. The emission factors are not specific to any one facility. Emission factors for gray iron foundries and the ferroalloy industry are not included.

This study was accomplished by conducting a literature search to determine emissions and emission factors available in the literature. In addition to identifying the literature source for each emission factor, the range of values found, and the recommended best value with its rating are presented.

The recommendations of this study are to use the AP-42 emission factors wherever possible and to use the emission factors developed for the 1985 NAPAP Emissions Inventory when AP-42 emission factors are unavailable. Other work uncovered in the literature search represented older studies conducted primarily on uncontrolled sources.

Little information existed on toxic air pollutant emission factors. The toxic air pollutant emission factors reported in the Toxic Air Pollutant Emission Factors - A Compilation for Selected Air Toxic Compounds and Sources should be used despite the limitations of that study. Additional work on quantifying the emissions of toxic air pollutants from the iron and steel industry should be conducted.

SECTION 1

INTRODUCTION

The objective of this study is to provide a comprehensive set of emission factors for sources of both criteria and toxic air pollutants in integrated iron and steel plants and specialty electric arc shops (mini-mills). Emission factors are to be identified for process sources, process fugitive and open source fugitive emissions. The emission factors are not to be specific to any one facility. Emission factors for gray iron foundries and the ferroalloy industry are not included.

This study was accomplished by conducting a literature search to determine emissions and emission factors available in the literature. In addition to identifying the literature source for each emission factor, the range of values found, and the recommended best value with its rating are presented.

SECTION 2

POLLUTANT EMITTING PROCESSES

Production of steel at an integrated iron and steel plant generally consists of several interrelated processes. The major operations include 1) coke production, 2) sinter production, 3) iron production, 4) iron preparation, 5) steel production, 6) semifinished product preparation, 7) finished product preparation, 8) heat and electricity supply and 9) handling and transport of raw, intermediate and waste materials.[1] A brief summary description of each of these operations is given below.

COKE MANUFACTURING

Coke is formed by heating coal in a very low oxygen atmosphere at high temperatures. This process is known as coking and is done in coke ovens, which are made of silica bricks. These ovens (normally 40 to 100) are connected by ducts and are referred to as a coke battery. Approximately 99 percent of all coke produced in the U.S. is produced by the byproduct recovery (slot oven) process.

Coal is transferred from storage piles by conveyer belts to a larry car that runs along the top of the coke battery and charges (fills) the ovens through ports in the top.

Following charging, the coal is leveled by a bar to allow for more even heating. The coal is heated at temperatures of 2000°-2100°F for 16-20 hours. The finished coke is pushed from the oven by a metal arm called a pushing ram. This is done through doors in the sides of the oven.

The hot coke is pushed into a quenching car (a specially designed railroad car). The quenching car moves the coke to the quenching tower, where several thousand gallons of water are poured over the coke to cool it. The coke is allowed to dry and is separated into various sizes for future uses.

The volatile matter driven off from the coal mass during the coking process is collected from each oven and piped to an adjacent "byproduct recovery plant" for recovery of coal byproducts, including coke oven gas which is returned to heat the ovens. Only about 40% of the recovered coke oven gas is used to continue heating the ovens. The remainder is utilized for other purposes throughout the plant.[1-3]

Particulates, volatile organic compounds, carbon monoxide, and other emissions are generated at several points in the coking process: 1) coal preheating (if used), 2) charging of coal into the coke oven, 3) oven leakage during the coking period, 4) pushing the coke out of the ovens, 5) quenching or cooling the hot coke, and 6) combustion stacks leading from oven underfiring operations. Oven charging and leakage around poorly sealed coke oven doors and lids are major sources of emissions from the coking process.

The gaseous emissions from the ovens during the coking process are drawn off and are subjected to various operations for separating ammonia, coke oven gas, tar, phenol, light oil (benzene, toluene, and xylene), and pyridine. After separation, these gases become a potential energy source for other areas of the steel mill. However, if the coke oven gas is not desulfurized, the combustion process will emit sulfur dioxide.[1]

SINTERING PLANTS

The sintering process converts fine raw materials like fine iron ore, coke breeze, limestone, mill scale, and flue dust into particles suitable in size for charging into a blast furnace. In doing this the materials are mixed with water (to provide cohesion) in a mixing mill and are placed on a continuous moving grate called the sinter strand. A burner hood above the front third of the sinter strand ignites the coke in the mixture. Once ignited combustion is self supporting and provides sufficient heat, 2400°-2700°F, to cause surface melting and agglomeration of the mix.

The fused sinter is discharged at the end of the sinter machine, where it is crushed and screened, and any undersized particles are recycled into the mixing mill.

The remaining sinter is cooled in open air, by water spray, or by fans to draw off the heat. The cooled sinter is screened a final time, with the fine particles being recycled and the rest being sent to charge the blast furnaces.

Emissions occur at several points in the process. Points of particulate generation are the windbox (vents that lie underneath the sinter machine and draw combusted air through the materials bed into a duct to a particulate control device), the discharge area (sinter crusher and hot screening), the cooler and the cold screening. In addition, in-plant transfer stations generate emissions which can be controlled by local enclosures. All the above sources except the cooler normally are vented to one or two control systems.

BLAST FURNACES

Blast furnaces are large refractory (resistance to melting at very high temperatures) lined chambers that are used to produce pig iron for conversion into steel. These are charged (filled) with iron, which can be in the form of natural ores or agglomerated products such as pellets or sinter, coke, and limestone. These products are allowed to react with large amounts of hot air to produce molten iron. The molten iron and slag collects in the hearth at the base of the furnace. The iron and slag are removed (cast) from the furnace periodically. The casting process involves drilling a taphole in the clay filled iron notch at the base of the hearth. The molten iron flows into runners that lead to transport ladles. Slag flows through separate runners that lead to a slag pit.

Emissions occur at several points in the iron making process. The first place they can occur is during the charging of the furnace. The major source of emissions is the casting process (especially for particulate emissions).

Emissions can also occur during slips. Slips occur when a layer of material does not settle with the rest of the material while it melts. This leaves a gas filled space between the two layers of material. The unsettled layer may collapse forcing the trapped gases up. This can cause the gas pressure to increase above the safety limit, thus opening a pressure relief valve and releasing the gases to the atmosphere.

Emissions may also occur if the facility utilizes a hot metal desulfurization process to remove sulfur from the molten pig iron following blast furnace production of iron.

These emissions are controlled by hoods (vents) used over the furnace and hoods in the roof of the building.[1,4]

STEEL PRODUCTION - BASIC OXYGEN PROCESS FURNACE

A basic oxygen process furnace is a large, open-mouthed vessel lined with a basic refractory material. The furnace is mounted on trunnions that allows it to be rotated through 360° in either direction. A typical vessel can have an opening 12 to 14 feet in diameter and be 20 to 30 feet high. Two types of furnaces are in general use. The most common type is the "top blown" furnace, in which oxygen is blown into the vessel through a lance inserted through the mouth of the furnace. The second type furnace, commonly known as a Q-BOP, is "bottom blown". Oxygen in these furnaces is added through tuyeres (nozzles) in the furnace bottom.

The furnace is filled with scrap and molten iron which it converts to molten steel. This is accomplished through the introduction of high-purity oxygen that reacts with the carbon and silicon in the molten iron, removes these products, and provides heat for melting the scrap. After the oxygen blow is started, lime may be added to the vessel to provide a slag of the desired basicity. Fluorspar may also be added to achieve the desired slag fluidity.

After the oxygen has been blown in, the furnace is turned down or tilted to one side so hot metal samples and temperature reading can be taken. If the samples taken during the turndown indicates the need, oxygen can again be blown into the furnace. This additional oxygen is usually only added for a very brief period.

The next step is to pour the molten steel out of the furnace into the teeming ladle (a large bucket). The teeming ladle is then used to pour the molten steel into the ingot molds. The last step is to pour the residual slag out of the furnace into a slag pot. The furnace is now ready to begin the cycle again.[5]

There are several sources of emissions in basic oxygen process furnace steel production. Emissions are produced at the furnace mouth during the refining (melting) of the scrap and molten iron. These emissions are collected by a hood (vent) placed over the mouth of the furnace.

Emissions are also produced during the transfer of the hot metal to the teeming ladle, from charging (filling) the furnace with scrap and hot metal. Also, during the dumping of the residual slag and molten steel into the ingot molds. In these processes, as in the first, the emissions are controlled by hoods placed over the process.[1]

Figure 1 shows the steps and emission hoods placement for the various phases of steel production by the basic oxygen process.

STEEL PRODUCTION - OPEN HEARTH FURNACES

An open hearth furnace is a shallow, refractory-lined basin in which scrap and molten iron are melted and refined into steel. Scrap is charged to the furnace through doors in the furnace front and molten metal is charged by pouring from a ladle through a trough positioned in the door. Melting heat is provided via gas burners above and at the sides of the furnace. Refining of the metal is accomplished by oxidation of the carbon in the metal and generation of a limestone slag that removes impurities. Most furnaces are equipped with oxygen lances to reduce the melting and refining times. Steel is removed from the furnace by opening a hole in the base with an explosive charge. Processing with an open hearth furnace typically requires 4 to 10 hours for each heat.

Emissions from open hearth steel production vary considerably. Oxygen lancing increases emissions of dust and fumes. Exhaust gas drawn from the furnace passes through a slag pocket and a regenerative checker chamber. These emissions, mostly iron oxides, are then ducted to an ESP or wet scrubber. Other furnace processes produce fugitive emissions which are usually uncontrolled.[1]

STEEL PRODUCTION - ELECTRIC ARC FURNACE

The process description for electric arc furnace steel production is described below as part of the process description for steel foundries.

STEEL FOUNDRIES

Steel foundries produce steel castings by the melting, alloying and molding of pig iron and steel scrap. The major processing operations of a typical steel foundry are raw materials handling, metal

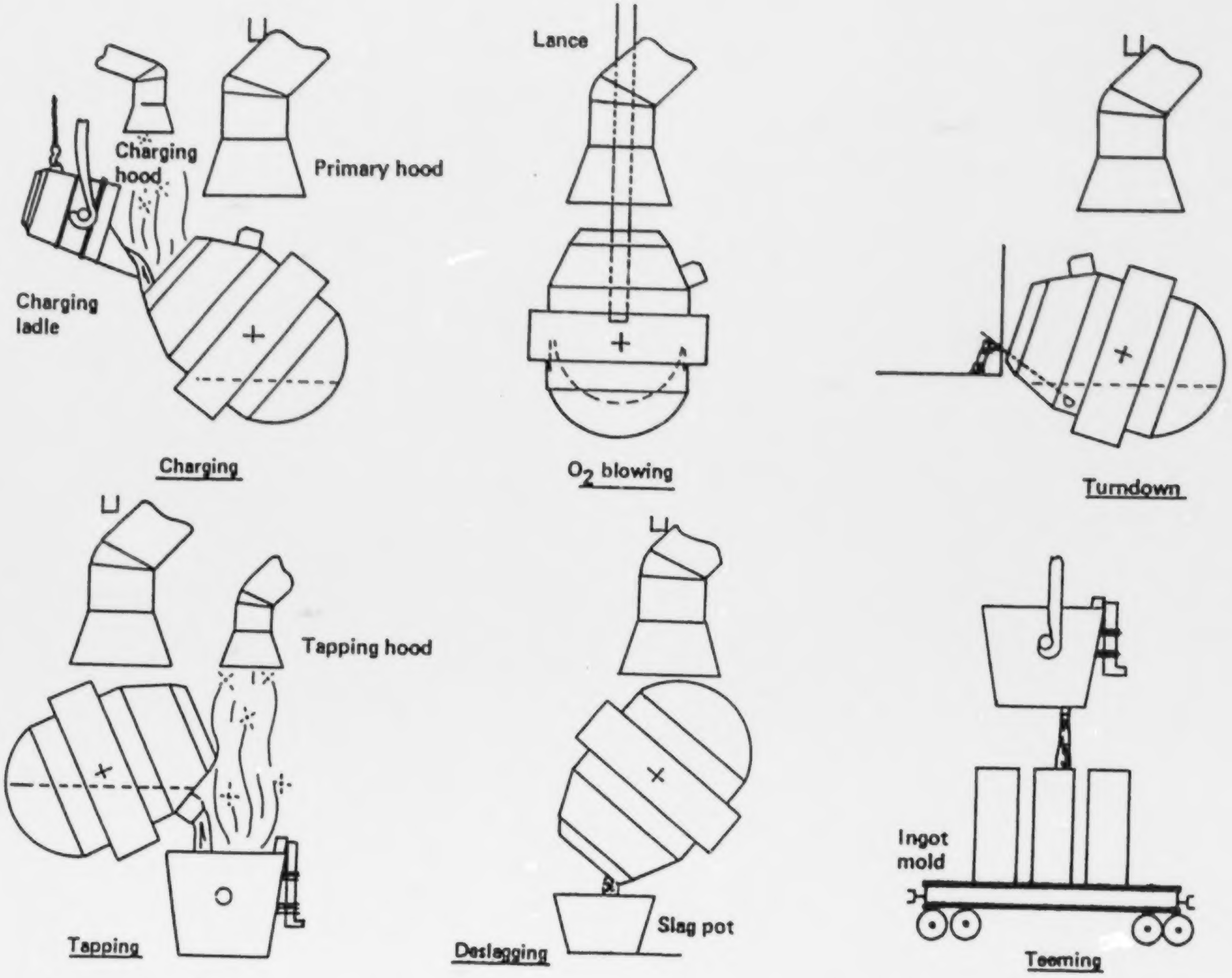
Charging hood
Primary hood
Charging ladle
Charging
Lance
O_2 blowing
Turndown
Tapping hood
Tapping
Deslagging
Slag pot
Ingot mold
Teeming

Figure 1. Steps for Making Steel by the Basic Oxygen Process.

melting, mold and core production, casting, and finishing.

The raw material handling operations included the receiving, unloading, storage and conveying of all raw materials for the foundry. Some of the material used by steel foundries are pig iron, iron and steel scrap, metal turnings, alloys, carbon additives, fluxes (limestone, soda ash, fluorspar, calcium carbide), sand, sand additives, and binders. These raw materials are transferred by trucks, loaders, and conveyors to both open piles and enclosed storage areas. They are then transferred by the same means to the various processes.

Emissions from raw material handling operations are particulates generated from the moving and storage of raw materials. These emissions are controlled by enclosing the major emission points and passing the air from enclosures through fabric filters.

The first step in metal melting is to clean all organic compounds from the metal. The metal may be cleaned with solvents or by burning them off. After the metal is cleaned, it is placed in an electric arc furnace for melting. Electric arc furnaces are large refractory lined steel pots, fitted with a refractory roof through which three graphite electrodes are inserted. The metal is melted by heat generated by the electrical current flowing among the electrodes and through the metal. The furnaces are charged by removing the lid or by using a door on the side of the furnace. During the melting process, the furnace remains closed. The next step is back charging, which is the addition of more metal and possibly some alloys. This also helps to adjust the carbon content. Now oxygen is injected through an oxygen lance to dislodge slag and to adjust the chemistry of the metal. The molten metal and slag is then tapped by tilting the furnace and pouring the metal through a hole in the side.

Emissions from cleaning the metal consist of hydrocarbons if solvents were used, and smoke, organic compounds and carbon monoxide if burning is used.

Emissions from the melting furnaces are particulates, carbon monoxide, organic compounds, sulfur dioxide, nitrogen oxide, and small quantities of chlorides and fluorides. The highest concentrations of furnace emissions occur during charging, back charging, oxygen lancing, slag and molten metal removal, and when the furnace lid and doors are open.

These emissions are controlled by venting the gases directly to an emissions control system (filters). Fugitive emissions not collected by these vents are controlled by hoods in the building's roof or by special hoods near the furnace doors. The capture efficiencies of the collection system usually range from 80 to 100 percent.

SEMIFINISHED PRODUCT AND FINISHED PRODUCT PRODUCTION

Mold and Core Production

Cores are forms used to make the inside shape of castings, and molds are forms used to shape the outside of the castings. Cores and molds are made of sand with clay and organic additives. The molten metal is poured (teemed) into the molds and cores and allowed to cool under carefully controlled rates. When partially cooled, the castings are placed on a vibrating grid, and the sand is shaken away from the casting. This sand is then recycled. The castings are now cleaned and smoothed (scarfed) to remove any sand or rough places. This is usually done by shot blasting.

Emissions from Mold And Core Production

The major pollution from these processes are particulates coming from the sand mold and cores. Some volatile organic compounds (VOC) and CO are also released. The particulates are controlled by bag filters and high energy scrubbers. Afterburners and catalytic incinerators can be used to control VOC and CO.

Miscellaneous Combustion Sources

The energy requirements for iron and steel plant operations are typically meet by a number of combustion sources. These combustion sources include blast furnace stoves, boilers, soaking pits and reheat furnaces. The fuels utilized by these sources include combinations of coal, fuel oil, natural gas, coke oven gas, and blast furnace gas. The combustible component of blast furnace gas is CO which burns clean. The major combustible component of coke oven gas is methane and it is thus similar to natural gas combustion. Emissions from coal, fuel oil and natural gas boilers are well documented.

SECTION 3

CRITERIA POLLUTANT EMISSION FACTORS

U.S. EPA publication AP-42, Compilation of Air Pollutant Emission Factors[1] is generally utilized to provide guidance on emission factors for criteria pollutants. For the nine major operations at iron and steel plants identified above, the sections of AP-42 that deal specifically with emissions from these operations can be identified. To help users understand the reliability and accuracy of AP-42 emission factors, each Table (and sometime individual factors with a Table) is given a rating (A through E, with A being the Best) which reflects the quality and the amount of data on which the factors are based. In general, factors based on many observations or on more widely accepted test procedures are assigned higher rankings. For instance, an emission factor based on ten or more source tests on different plants would likely get an A rating, if all tests were conducted using a single valid reference measurement method or equivalent techniques. Conversely, a factor based on a single observation of questionable quality, or one extrapolated from another factor for a similar process, would probably be labeled D or E. Several subjective schemes have been used in the past to assign these ratings, depending upon data availability, source characteristics, etc. Because these ratings are subjective and take no account of the inherent scatter among the data used to calculate factors, they should be used only as approximations, to infer error bounds or confidence intervals about each emission factor. At most, a rating should be considered an indicator of the accuracy and precision of a given factor used to estimate emissions from a large number of sources. This indicator will largely reflect the professional judgement of the authors and reviewers of AP-42 Sections concerning the reliability of any estimates derived with these factors. The rating scheme used in this report is summarized below.

A	Developed from A-rated test data from many randomly chosen facilities in the industry population.
B	Developed only A-rated test data from a reasonable number of facilities.
C	Developed only from A- and B-rated test data from a reasonable number of facilities.
D	Developed from only A- and B-rated test data from a small number of facilities.
E	Developed from C- and D-rated test data and there may be reason to suspect that the facilities tested do not represent a random sample of the industry.

Listed below are the major operations and the corresponding AP-42 section(s) pertaining to criteria pollutant emissions. Copies of the appropriate sections of AP-42 are included in Appendix A for the readers convenience. A location index is listed below.

o Coke production

AP-42 Section 7.2 Coke Manufacturing (Page A-52)
AP-42 Section 6.18 Ammonium Sulfate Manufacture (Page A-42)

o Sinter Production

AP-42 Section 7.5 Iron and Steel Production (Page A-75)

o Iron Production

AP-42 Section 7.5 Iron and Steel Production (Page A-75) o Iron Preparation

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o Steel Production

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o Semifinished Product Preparation

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o Finished Product Preparation

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o Heat and Electricity Supply

AP-42 Section 1.1 Bituminous and Subbituminous Coal Combustion (Page A-2)
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o Handling and Transport of Materials

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AP-42 Section 11.2 Unpaved Road (Page A-96)

The primary information available from AP-42 regarding criteria pollutant emissions from iron and steel plants pertains to particulate emission factors. Review of the above sections of AP-42 revealed that little information was available on the other criteria air pollutants (SO_2, NO_x, VOCs, and CO). Emission factors for both controlled and uncontrolled processes are published in AP-42, but the control devices typically refer to particulate control devices, not control devices for other criteria pollutants.

Additional emission factors for criteria pollutants (especially non-particulate pollutants) have been developed as part of the National Acid Precipitation Assessment Program (NAPAP).[6] The major objective of that work was to develop VOC emission factors for SCC codes that had no emission factors in either AP-42 (4th Edition) or AP-42, Supplement A. Also included in that work was the development of NO_x and SO_2 emission factor estimates for SCC's which were included in reports submitted by the States that previously lacked these factors. The new emission factors that resulted from this work were not of the same quality as those found in AP-42. These factors represent best estimates and were generated from estimates taken from the literature, from averaging of data submitted by 13 State air quality offices, and through technology transfer of emission factors for SCC's from similar industries. The emission factors generated in the NAPAP work have been rated E due to a lack of rigorous quality assurance. In some cases, the new emission factors may be of higher quality than this "E" rating implies. Emission factors for the processes involved in iron and steel production developed as part of the NAPAP work are presented in Table 1. The emission factors developed for the NAPAP emission inventory normally represent uncontrolled emissions. For PM_{10} emission factors, AP-42 should be consulted since the particulate emission factors developed as part of the NAPAP effort were for TSP, not PM_{10}.

Table 1. Criteria Pollutant Emission Factors Developed for the NAPAP Emissions Inventory

SCC	Process	SO_x Lbs/Unit	NO_x Lbs/Unit	VOC Lbs/Unit	CO Lbs/Unit	Units
Process Gas						
1-02-007-04	Blast Furnace Gas	*950.0 S^c	*23.0^d	*0.0^d	*13.7^d	10^6 Cubic Feet Burned
1-02-007-07	Coke Oven Gas	*680.0 S^c	*80.0^d	*1.2^d	*18.4^d	10^6 Cubic Feet Burned
By-Product Coke Manufacturing - 3312						
3-03-003-02	Oven Charging	0.02	0.03	2.5	0.6	Tons Coal Charged
3-03-003-03	Oven Pushing	*3.3	*0.03	0.2	0.07	Tons Coal Charged
3-03-003-04	Quenching	*0.4	*0.6	*0.02		Tons Coal Charged
3-03-003-05	Coal Unloading	0.0	0.0	0.0	0.0	Tons Coal Charged
3-03-003-06	Oven Underfiring	4.0	*0.04	*2.0		Tons Coal Charged
3-03-003-07	Coal Crushing/Handling	0.0	0.0	0.0	0.0	Tons Coal Charged
3-03-003-08	Oven/Door Leaks	*0.1	0.01	1.5	0.6	Tons Coal Charged
3-03-003-09	Coal Conveying	0.0	0.0	0.0	0.0	Tons Coal Processed
3-03-003-10	Coal Crushing	0.0	0.0	0.0	0.0	Tons Coal Processed
3-03-003-11	Coal Screening	0.0	0.0	0.0	0.0	Tons Coal Processed
3-03-003-12	Coke Crushing/Screening/Handling	0.0	0.0	0.0	0.0	Tons Coke Processed
3-03-003-13	Coal Preheater			*0.3		Tons Coal Charged
3-03-003-14	Topside Leaks	*0.1	*0.01	*1.5		Tons Coal Charged
3-03-003-15	Gas By-Product Plant			0.0		10^6 Cubic Feet Gas Processed
Iron Production - 3312						
3-03-008-01	Blast Furnace: Ore Charge	0.0	0.0	0.0	*1,750.0^{c,t}	Tons Iron Produced
3-03-008-02	Blast Furnace: Agglomerates Charge	0.0	0.0	0.0	0.0	Tons Iron Produced
Blast Furnace Slag						
3-03-008-04	Loader: Hi-Silt	0.0	0.0	0.0	0.0	Tons Slag Transferred
3-03-008-05	Loader: Lo-Silt	0.0	0.0	0.0	0.0	Tons Slag Transferred
3-03-008-08	Slag Crushing and Sizing	*0.0	*0.0	*0.0		Tons Processed
3-03-008-09	Slag Removal and Dumping	*0.0	*0.0	*0.0		Tons Processed
Sintering - 3312						
3-03-008-11	Raw Material Stockpiles, Coke Breeze, Limestone, Ore Fines			*4.8		Tons Sinter Produced
3-03-008-12	Raw Material Transfer/Handling			*0.0		Tons Sinter Produced
3-03-008-13	Windbox	*2.5^d	*0.3^d	*1.4^d	44.0	Tons Sinter Produced
3-03-008-14	Sinter Discharge End	*NEG	*NEG	*0.0		Tons Sinter Produced
3-03-008-15	Sinter Breaker			*0.0		Tons Sinter Produced
3-03-008-16	Sinter Hot Screening	*0.0	*0.0	*0.0		Tons Sinter Produced
3-03-008-17	Sinter Cooler	*0.14	*NEG	*NEG		Tons Sinter Produced
3-03-008-18	Sinter Cold Screening	*0.0	*0.0	*0.0		Tons Sinter Produced
3-03-008-19	Sinter Processing (Combined Code Includes 15, 16, 17, 18)			*0.05		Tons Sinter Produced
3-03-008-20	Sinter Conveyor: Transfer Station	0.0	0.0	0.0	0.0	Tons Sinter Transferred
3-03-008-21	Unloading Ore, Pellets, Limestone into Blast Furnace	0.0	0.0	0.0	0.0	Tons Ore Transferred

Table 1. (continued)

SCC	Process	SO_x Lbs/Unit	NO_x Lbs/Unit	VOC Lbs/Unit	CO Lbs/Unit	Units
Sintering - 3312 (Continued)						
3-03-008-22	- Blast Furnace Raw Materials Stockpiles: Ore, Pellets, Limestone, Coke, Sinter			*4.8		Tons Processed
3-03-008-23	- Blast Furnace Charge Materials Transfer/Handling			*0.0		Tons Processed
3-03-008-24	- Blast Heating Stoves			*0.01		Tons Processed
3-03-008-25	- Cast House	*3.0	*0.03	*2.8		Tons Processed
3-03-008-26	- Blast Furnace Slips			*0.0		Number of Slips
3-03-008-27	- Lump Ore Unloading	0.0	0.0	0.0	0.0	Tons Ore Transferred
Fugitive Emissions: Roads						
3-03-008-31	- Unpaved Roads: LDV	0.0	0.0	0.0	0.0	Vehicle-Miles Traveled
3-03-008-32	- Unpaved Roads: MDV	0.0	0.0	0.0	0.0	Vehicle-Miles Traveled
3-03-008-33	- Unpaved Roads: HDV	0.0	0.0	0.0	0.0	Vehicle-Miles Traveled
3-03-008-34	- Paved Roads: All	0.0	0.0	.0.0	0.0	Vehicle-Miles Traveled
Steel Production - 3312						
3-03-009-01	- Open Hearth Furnace: Stack	*1.4		*0.17		Tons Produced
3-03-009-04	- Electric Arc Furnace: Stack (Alloy Steel)	*0.7	*0.1	*0.35	18.0	Tons Produced
3-03-009-06	- Charging: EAF			*0.001		Tons Produced
3-03-009-07	- Tapping: EAF			*0.002		Tons Produced
3-03-009-08	- Electric Arc Furnace: Stack (Carbon Steel)	*0.7	*0.1	*0.35	18.0	Tons Produced
3-03-009-10	- Pickling	*0.0	*0.0	*0.0		Tons Produced
3-03-009-11	- Soaking Pits	*NEG	*NEG	*0.02		Tons Produced
3-03-009-12	- Grinding	*0.0	*0.0	*0.0		Tons Produced
3-03-009-13	- Basic Oxygen Furnace: Open Hood-Stack		*0.08	*0.001	139.0^u	Tons Produced
3-03-009-14	- Basic Oxygen Furnace: Closed Hood-Stack			*0.001	139.0^u	Tons Produced
3-03-009-15	- Hot Metal (Iron) Transfer to Steelmaking Furnace			*0.001		Tons Produced
3-03-009-16	- Charging: BOF			*0.001		Tons Produced
3-03-009-17	- Tapping: BOF		*0.02	*0.002		Tons Produced
3-03-009-18	- Charging: Open Hearth			*0.001		Tons Produced
3-03-009-19	- Tapping: Open Hearth			*0.002		Tons Produced
3-03-009-21	- Teaming (Unleaded Steel)			*0.002		Tons Produced
3-03-009-22	- Continuous Casting		*0.05	*NEG		Tons Produced
3-03-009-23	- Steel Furnace Slag Tapping and Dumping			*0.002		Tons Produced
3-03-009-24	- Steel Furnace Slag Processing, Crushing and Sizing	*0.0	*0.0	*0.0		Tons Produced
3-03-009-25	- Teaming (Leaded Steel)			*0.002		Tons Produced
3-03-009-31	- Hot Rolling			*0.08		Tons Produced
3-03-009-32	- Machine Scarfing	*NEG	*NEG	*NEG		Tons Produced
3-03-009-33	- Reheat Furnaces	*0.8	*0.8	*0.01		Tons Produced

Table 1. (continued)

SCC	Process	SO$_x$ Lbs/Unit	NO$_x$ Lbs/Unit	VOC Lbs/Unit	CO Lbs/Unit	Units
Steel Production - 3312 (Continued)						
3-03-009-34	Heat Treating Furnaces, Annealing		*0.1	*0.004		Tons Produced
3-03-009-35	Cold Rolling		*	*0.56		Tons Produced
3-03-009-36	Coating (Tin, Zinc, etc.)		*1.9	*0.07		Tons Produced
3-03-009-98	Other Not Classified (Specify in Comments)					Tons Produced Each
3-03-009-99	Other Not Classified (Specify in Comments)					Tons Produced
Steel Foundry - 3324, 3325						
3-04-007-01	Electric Arc Furnace	*0.25	0.2	*0.35		Tons Processed
3-04-007-02	Open Hearth Furnace		0.01	*0.17		Tons Processed
3-04-007-03	Open Hearth Furnace with Oxygen Lance		0.0	*0.17		Tons Processed
3-04-007-04	Heat-Treating Furnace	*470	*80	*0.02		Tons Processed
3-04-007-05	Electric Induction Furnace	0.0	0.0	0.0	0.0	Tons Processed
3-04-007-06	Sand Grinding/Handling in Mold and Core Making	*0.0	*0.0	*0.0		Tons Processed
3-04-007-07	Core Ovens	*0.32	*0.05	*0.0008		Tons Processed
3-04-007-08	Pouring and Casting	*0.02	*0.01	*0.14		Tons Metal Processed
3-04-007-09	Casting Shakeout		*2.4	*1.2		Tons Metal Processed
3-04-007-10	Casting Knockout			*1.2		Tons Sand Handled
3-04-007-11	Castings Cleaning	*0.0	*0.0	*0.0		Tons Metal Processed
3-04-007-12	Charge Handling			*0.0		Tons Metal Processed
3-04-007-13	Castings Cooling	*NEG	*NEG	*NEG		Tons Metal Processed
3-04-007-14	Shakeout Machine	*0.0	*0.0	*1.2		Tons Sand Handled
3-04-007-15	Finishing: Specify in Comments	*0.4	*87	*1.1		Tons Metal Processed
3-04-007-16	Sand Grinding and Handling	*0.0	*0.0	*0.0		Tons Metal Processed
3-04-007-17	Core Ovens	*0.32	*0.05	*0.0008		Tons Metal Processed
3-04-007-18	Core Ovens	*0.33	*0.05	*0.0008		Gallons Core Oil Used
3-04-007-20	Sand Dryer	*0.002	*1.6	*0.004		Tons Sand Handled
3-04-007-21	Sand Silo	*0.0	*0.0	*0.0		Tons Sand Handled
3-04-007-22	Muller	*0.0	*0.0	*0.0		Tons Sand Handled
3-04-007-23	Conveyors/Elevators	*0.0	*0.0	*0.0		Tons Sand Handled
3-04-007-24	Sand Screens	*0.0	*0.0	*0.0		Tons Sand Handled
3-04-007-25	Casting Cleaning/Tumblers	*0.0	*0.0	*0.0		Tons Castings Cleaned
3-04-007-26	Casting Cleaning/Chippers	*0.0	*0.0	*0.0		Tons Castings Cleaned
3-04-007-30	Shell Core Machine	*0.32	*0.5	*0.0008		Tons Cores Produced
3-04-007-31	Core Machines/Other	*0.32	*0.5	*0.0008		Tons Cores Produced
3-04-007-99	Other Not Classified (Specify in Comments)					Tons Processed

COKE PRODUCTION

Emission factors for coking operations listed in Section 7.2 of AP-42 include factors for particulates, SO_2, CO, VOCs, NO_x and ammonia for some of the operations involved in producing coke. The majority of the information on emissions from coking operations presented in Section 7-2 of AP-42 concerns particulate emissions. Table 7.2-1 from AP-42 (page A-52, of this report) summarizes the emission factors available from AP-42 for coking operations. Information on particle size specific emission factors for some coking operations is available in Table 7.2-2 of AP-42 (page A-60, of this report).[1] The information utilized to develop the emission factors in AP-42 for particulate emissions can be found in reference 2.

With the exception of those developed for particulate emissions, the emission factors given in AP-42 for coke production processes are rated D. Particulate emission factor ratings for the various processes involved in the manufacture of coke for iron and steel production range from A to E. Ratings for each individual process particulate emission factor are given in Table 7.2-1 from AP-42 (page A-58, of this report).

Emission factors for non-particulate criteria pollutants are listed in Table 1. Emission factors in this list without asterisks are the same as AP-42 and thus have the same ratings as those found in Appendix A. The remaining emission factors listed in Appendix B were developed as part of the NAPAP emissions inventory and are rated E.

Section 6.18 of AP-42 contains particulate emission factors from dryers used in the production of ammonium sulfate by a variety of processes including coke oven byproduct plants. For uncontrolled emissions from rotary dryers, particulate emissions are 46 lb./ton of ammonium sulfate produced. Wet scrubber controlled rotary dryers emit 0.24 lb./ton. Fluidized bed dryers emit 218 lb./ton if uncontrolled and 0.28 lb./ton if wet scrubber controlled. These emission factors are rated B, however, it should be noted that these emissions reflect TSP emissions and do not have any additional particle size information available.

IRON AND STEEL PRODUCTION

Emission factors from AP-42 for iron and steel production include emission factors for the following processes:

Sinter production
Iron production by blast furnace
Iron preparation
Steel production (by a variety of methods)
Semifinished and finished product preparation
Miscellaneous combustion sources

As with coke production, AP-42 emission factors for iron and steel production are primarily available for particulate emissions and are published in Section 7.5 of AP-42. These emission factors are listed in Table 7.5-1 of AP-42 (page A-81, of this report). Size specific particulate emission factors from AP-42, Section 7.5 are listed in Table 7.5-2 (page A-85, of this report). Particulate emission factors listed in AP-42 are rated from A to E depending on the process. Some controlled particulate emission factors are also given in the Appendix A listing.

The only other information published in AP-42 on criteria pollutants emitted during iron and steel production concerns uncontrolled CO emissions. The data presented for this pollutant in AP-42 is very limited. Only three processes involved in the production of iron and steel have emission factors in AP-42. Each of these emission factors is for uncontrolled emissions. No information is available for controlled emissions of CO. The emission factors listed for CO in AP-42 are rated C.

Emission factors for the other criteria pollutants are available for iron and steel production from the NAPAP emission factor work. The emission factors for SO_2, NO_x and VOC available from this work are listed in Table 1. As stated previously, all emission factors in the NAPAP listing are rated E.

Additional information on some of the processes involved in steel production (especially specialty shops and mini-mills) can be found in AP-42, Section 7.13. This section has limited information on emission factors for steel foundries. Emission factors for particulates and NO_x are given. However, the particulate emission factor is for TSP and no additional information on particle size distribution is given.

Additional information on non-particulate criteria pollutant emissions from steel foundries can be found in the NAPAP emission factor section in Table 1.

HEAT AND ELECTRICITY GENERATION

Miscellaneous combustion sources at iron and steel plants is provided by blast furnace stoves, boilers, soaking pits and reheat furnaces. These facilities burn a combination of coal, fuel oil, natural gas, coke oven gas and blast furnace gas. Emission factors available in Sections 1.1 through 1.4 of AP-42 can be utilized to evaluate emissions from coal, natural gas and fuel oil combustion sources located at iron and steel plants. These sections are included in Appendix A for the readers convenience. Emission factor ratings for the various combustion configurations is also given in the information in Appendix A.

Criteria pollutant emissions from combustion of coke oven gas and blast furnace gas has been estimated as part of the NAPAP emission factor development work. The pertinent information from that work is included in Table 1. As mentioned above, all emission factors developed for NAPAP are rated E.

MATERIAL TRANSPORT, STORAGE AND HANDLING

Transport, handling and storage of materials (both raw and waste) generates emissions of criteria pollutants. These activities generate almost exclusively particulate emissions. AP-42, Section 11.2 deals with particulate emissions from fugitive dust sources such as aggregate handling and storage pile operations, emissions from vehicle traffic on paved and unpaved roads around the plant, and wind erosion. Section 11.2 of AP-42 is included in Appendix A for the readers convenience. Emission factors for these source types are generally rated very highly (typically A or B) however, these ratings are variable and depend on the values of the correction parameters used.[1]

Emission factors for material transport, storage and handling for iron and steel plants are also given in Section 7.5 of AP-42, but the emission factors given are not as highly rated as those in Section 11.2. Thus preference should be given to the emission factors in Section 11.2.

OTHER SOURCES OF INFORMATION

Additional work has been done to try and establish VOC emission factors from all sectors of the ferrous metallurgy industry (which includes iron and steel, iron foundries and ferroalloy industries).[7] Results of this work indicated that, at the time of the study, the available emissions data did not include specific measurements of VOC emissions. As a consequence, organic emission factors were developed (which included non-volatile as well as volatile organic compounds). These organic emission factors are thought to represent an upper limit (since they include non-VOC organics). Ratings for these organic emission factors are either C or D. Table 2 lists the emission factors and ratings developed in this study for processes in the iron and steel industry.

Part of the problem in developing emission factors for VOC in the study mentioned above was

Table 2. Summary of Organic Emission Factors for the Iron and Steel Industry

	Organic emission factor		Normalized organic emission factor (lb/ton)[b]
	(lb/ton)[a]	Rating	
Iron and Steel Industry[c]			
Byproduct cokemaking	11.5	C	3.90
Blast furnace ironmaking	1.98	D	1.17
Sinter production	4.80	C	3.20
Basic oxygen process steelmaking	0.0029	C	0.0018
Electric arc furnace steelmaking	0.348	C	0.0995
Open hearth furnace steelmaking	0.168	-	0.0188
Hot forming and finishing operations	0.643	D	0.184
Total	-	-	8.57

[a] Emission factors based on ton of process or operation product output (e.g., coke, iron, sinter, etc.).

[b] Emission factors normalized to lb/ton finished product (i.e., total steel products, net castings, total ferroalloys).

[c] 1981 Steel production 120,828,000 tons.

that organic emissions are typically grouped into a number of subclassifications such as hydrocarbons, organic solvents, polynuclear organic materials (POM), VOCs, benzene soluble organics (BSO), polycyclic aromatic hydrocarbons (PAH), gravimetric organics and extractable organics. Many of these subclasses are not mutually exclusive with some compounds belonging to several classes. A second problem is the large number of organic compounds (both volatile and non-volatile) generated by iron and steel processes. As an example, Tables 3 and 4 list compounds (both organic and inorganic) identified just from coke production. Table 5 lists PAH compounds identified on particulates generated from coke production.[8]

Earlier studies have also produced emission factors for CO, NO_x, SO_x and particulates.[9] Particulate matter and trace constituents (including CO, NO_x and SO_x) emission factors from electric arc furnaces have also been presented in older studies.[10] Electric arc furnaces were found to produce particulate emissions of 15-40 lb./ton during melting and refining operations and 1.6-2.0 lb./ton during charge and tap operations. Both of these emission factors are for TSP emissions and represent uncontrolled conditions.

Electric arc furnace emission factors for CO, NO_x and SO_x in this study were 0.52-6.5 lb./ton, 0.1 lb./ton, and 0.01 lb./ton, respectively. Again, these emission factors are for uncontrolled emissions and in this case represent emissions for total electric arc furnace operations.

In the studies noted in this section it is virtually impossible to assess the quality of the emission factors. Most of the emission factors developed in these studies have been for uncontrolled processes. Additionally, the emission factors developed as part of these studies are older than the information contained in either AP-42 or the NAPAP emission factor work.

RECOMMENDATIONS

Given the information presented above, we recommend that the emission factors in AP-42 be utilized whenever possible, especially for controlled processes. When this is not possible, then the NAPAP emission factors should be utilized.

Table 3. Partial List of Constituents of Coke Oven Emissions

POLYNUCLEAR AROMATIC HYDROCARBONS

Anthanthrene
Anthracene
Benzindene
Benz[a]anthracene
Benz[b]fluoranthene
Benzo[ghi]fluoranthene
Benzo[j]fluoranthene
Benzo[k]fluoranthene
Benzofluorene
Benzo[a]fluorene
Benzo[b]fluorene
Benzo[c]fluorene
Benzo[c]phenanthrene
Benzo[ghi]perylene
Benzo[a]pyrene
Benzo[e]pyrene
Benzoquinoline
Chrysene
Coronene
Dibenz[a,h]anthracene
Dibenzo[a,h]pyrene
Dihydroanthracene
Dihydrobenzo[a]fluorene
Dihydrobenzo[b]fluorene
Dihydrobenzo[c]fluorene
Dihydrobenz[a]anthracene
Dihydrochrysene
Dihydrofluoranthene
Dihydrofluorene
Dihydromethylbenz[a]anthracene
Dihydromethylbenzo[k and b]fluoranthenes
Dihydromethylbenzo[a and e]pyrenes
Dihydromethylchrysene
Dihydromethyltriphenylene
Dihydrophenanthrene
Dihydropyrene
Dihydrotriphenylene
Dimethylbenzo[b]fluoranthene
Dimethylbenzo[k]fluoranthene
Dimethylbenzo[a]pyrene
Dimethylchrysene
Dimethyltriphenylene
Ethylanthracene
Ethylphenanthrene
Fluoranthene
Fluorene
Indeno[1,2,3-cd]pyrene
Methylanthracene
Methylbenzo[a]anthracene
Methylbenzo[a]pyrene
Methylbenzo[ghi]perylene
Methylchrysene
Methylfluoranthene
Methylfluorene
Methylphenanthrene
Methylpyrene
Methyltriphenylene
Octahydroanthracene
Octahydrofluoranthene
Octahydrophenanthrene
Octahydropyrene
Perylene
Phenanthrene
Indeno[1,2,3-cd]pyrene
Pyrene
Triphenylene

POLYNUCLEAR AZA-HETEROCYCLIC COMPOUNDS

Acridine
Benz[c]acridine
Dibenz[a,h]acridine
Dibenz[a,j]acridine

AROMATIC AMINES

α-Naphthylamine
β-Naphthylamine

TRACE ELEMENTS

Arsenic
Beryllium
Cadmium
Chromium
Cobalt
Iron
Lead
Nickel
Selenium

(continued on the following page)

Table 3. (continued)

OTHER AROMATIC COMPOUNDS	OTHER GASES
Benzene	Ammonia
Phenol	Carbon disulfide
Toluene	Carbon monoxide
Xylene	Hydrogen cyanide
	Hydrogen sulfide
	Methane
	Nitric oxide

Table 4.

PAH Concentrations in Coke-Oven Emission[a]

Compound	Sample No. 1[b]		Sample No. 2[c]		Sample No. 3[d]		Sample No. 4[e]	
	Peak No.	Concentration, µg/g of sample	Peak No.	Concentration, µg/g of sample	Peak No.	Concentration, µg/g of sample	Peak No.	Concentration, µg/g of sample
Octahydrophenanthrene	1	31.85	--	--	--	--	--	--
Octahydroanthracene	1a	29.89	1	8.77	1	29.98	2	70.31
Dihydrofluorene	2	30.31	2	13.62	1a	15.68	2a	18.26
Dihydrofluorene	2a	18.76	--	--	--	--	2b	23.20
Benzindene	3	106.73	2a	6.72	2	58.15	2c	20.81
Fluorene	4, 4a	271.52	3	20.86	3	19.29	2d	15.37
Dihydrophenanthrene	4b, 5	586.98	4	79.55	4	316.49	3	325.83
Dihydroanthracene	6	168.88	5	21.92	5	101.68	4	232.54
2-Methylfluorene	7	98.71	6	9.06	5a	8.87	5	40.28
1-Methylfluorene	8	73.46	7	24.35	6	44.01		
9-Methylfluorene	9	44.32	8	11.81	7	6.71	6	102.83
Methylfluorene	10	87.84	9	10.77	--	--	6a	10.38
Benzoquinoline	11	77.74	10	8.34	8	31.41	7	79.77
Acridine	12, 12a	85.98	11	32.44	9	74.98	8	172.79
Phenanthrene	13	2,828.54	12	163.53	11	458.80	9	636.98
Anthracene	14	942.85	13	46.44	11a	305.89	9a	500.36
Fluorine carbonitrile	15	180.29	14	16.76	11b	32.55	9b	11.47
Methylphenanthrene	16	1,023.41	15	44.67	12	130.22	10	283.92
Methylanthracene	17	1,692.26	16	85.30	13	258.93	11	573.25
Ethylphenanthrene	18	1,578.60	17	58.04	14	202.97	12	197.39
Ethylanthracene	19	1,096.71	18	49.19	15	249.86	13	1,473.68
Octahydrofluoranthrene and octahydropyrene	20	280.42	19	11.06	16	64.36	13a	44.53
Dihydrofluoranthene	21	115.07	20	73.57	17	64.87	13b	31.86
Dihydropyrene	22	575.06	21	36.65	18	52.29	14	404.25
Fluoranthene	23	5,979.74	22	269.74	19	451.95	15	1,097.82
Dihydrobenzo[a]fluorene	24	791.41	23	24.03	--	--	--	--
Dihydrobenzo[b]fluorene and dihydrobenzo[c]-fluorene	25	213.53	24	28.77	20	99.07	16	46.38

Table 4. (continued)

	Sample No. 1[b]		Sample No. 2[c]		Sample No. 3[d]		Sample No. 4[e]	
Compound	Peak No.	Concentration, μg/g of sample	Peak No.	Concentration, μg/g of sample	Peak No.	Concentration, μg/g of sample	Peak No.	Concentration, μg/g of sample
Pyrene	26	4,627.33	25	206.35	21	472.09	17	1,446.64
Benzo[a]fluorene	27	971.18	26	87.42	22	62.97	17a	37.21
Benzo[b]fluorene	28	109.45	27	16.70			17b	22.63
Benzo[c]fluorene	29	627.02	28	38.96	23	290.03	17c	98.47
Methylfluoranthene	30	1,817.37	29	124.73	24	126.03	18	101.56
Methylfluoranthene	31	390.94	30	21.87	25	179.04	18a	34.83
Methylpyrene	32	1,016.76	31	31.12	26	97.80	19	120.66
Methylpyrene	33	856.91	32	106.34	27	233.37	20	175.42
Benzo[c]phenanthrene	34	220.45	33	82.70	28	1,510.34	21	2,156.14
Benzo[ghi]fluoranthene	35	677.35	34	164.25	29	201.74	21a	151.88
Dihydrobenz[a]anthracene, dihydrochrysene, and dihydrotriphenylene	36	383.03	34a	54.75	29a	101.78	22	271.38
Benz[a]anthracene	37	2,740.45	35	105.15	30	5,509.43	23	2,673.65
Chrysene and triphenylene	38	4,202.02	36	119.04				
Dihydromethylbenz[a]-anthracene, dihydromethylchrysene, and dihydromethyltriphenylene	39	841.67	37	93.30	30a	247.80	23a	86.35
Methylbenz[a]anthracene	40	159.33	38	22.36	31	1,015.70	24	1,669.72
Methyltriphenylene	41	463.99	39	40.81	32	371.97	25	369.10
Methylchrysene	42	1,151.61	40	107.50	33	193.68	26	449.19
Dihydromethylbenzo[k and b]fluoranthenes and dihydromethylbenzo[a and e]pyrenes	43	434.38	40a	8.63	34, 35	185.08	26a	137.26
Dimethylbenz[a]-anthracene, dimethyltriphenylene, and dimethylchrysene	44, 44a	246.35	41	46.73	36	174.71		
					37	62.25	27	160.89
					38	30.16	28	451.70
Benzo[j]fluoranthene	45	176.92	42	18.66	39	80.04	29	285.34
Benzo[k]fluoranthene and benzo[b]fluoranthene	46	3,930.34	43	155.03	40	2,170.92	30	2,556.98

Table 4. (continued)

Compound	Sample No. 1[b]		Sample No. 2[c]		Sample No. 3[d]		Sample No. 4[e]	
	Peak No.	Concentration, μg/g of sample	Peak No.	Concentration, μg/g of sample	Peak No.	Concentration, μg/g of sample	Peak No.	Concentration, μg/g of sample
Methylbenzo[k]fluoranthene and methylbenzo[b]fluoranthene	47	735.95	44	33.05	41	430.05	31	492.13
Benzo[e]pyrene	48	103.86	--	--	--	--	--	--
Benzo[a]pyrene	48a	2,630.92	45	122.15	42	2,007.75	32	2,297.83
Perylene	49	702.12	46	22.07	43	616.85	33	698.44
Methylbenzo[a]pyrene	50	330.85	47	5.88	44	344.12	34	247.96
Dimethylbenzo[k]-fluoranthene and dimethylbenzo[b]-fluoranthene	51	116.74	--	--	45	73.13	--	--
Dimethylbenzo[a]pyrene	52	82.68	--	--	46	70.18	--	--
Dibenzanthracene	53	123.66	--	--	47	84.52	--	--
o-Phenylenepyrene	54	101.54	--	--	--	--	--	--
Benzo[ghi]perylene and anthanthrene	55	72.35	--	--	--	--	--	--
Methyldibenzanthracene	56	89.04	--	--	--	--	--	--
Methylbenzo[ghi]perylene	57	36.79	--	--	--	--	--	--
Coronene	58	864.55	--	--	51	833.30	35	766.58
Dibenzopyrene	59	693.21	--	--	52	587.05	36	493.27

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[a] Table derived from Reference 8.

[b] Glass-fiber filter No. 1: total weight of material collected, 12.59 mg; total volume of solvent extract, 1 ml; injected sample size, 10 μl.

[c] Glass-fiber filter No. 2: total weight of material collected, 39.67 mg; total volume of solvent extract, 1.0 ml; injected sample size, 10 μl.

[d] Silver membrane filter No. 1: total weight of material collected, 5.75 mg; total volume of solvent extract, 0.6 ml; injected sample size, 6 μl.

[e] Silver membrane filter No. 2: total weight of material collected, 1.96 mg; total volume of solvent extract, 1.0 ml; injected sample size, 10 μl.

Table 5.

Coke Oven PAH Emission on Particles as a Function of Particle Size

Size	>15 µm	7-15 µm	3-7 µm	0.9-3 µm	<0.9 µm
PAH	µg	µg	µg	µg	µg
Phenanthrene	0.5	0.5	0.8	2.0	a
Anthracene	0.3	0.2	0.6	0.7	a
Methylphenanthrene/ methylanthracene[b]	c	c	0.4	1.3	c
Fluoranthene	c	c	4.2	10.7	2.0
Dihydrobenzo[ab]-fluorene	c	c	0.6	2.1	c
Pyrene	c	c	4.3	12.3	1.3
Benzo[a]fluorene	c	c	3.5	9.1	0.5
Benzo[b]flourene	c	c	2.6	7.2	0.3
Benzo[c]phenanthrene	c	c	2.0	5.2	0.8
Benz[a]anthracene	0.03	0.08	3.3	9.0	4.0
Chrysene/triphenylene	0.06	0.10	5.8	13.2	1.8
Benzo[bjk]fluoranthene	0.05	0.40	4.8	10.6	7.2
Benzo[e]pyrene	0.03	0.14	3.4	8.9	0.5
Benzo[a]pyrene	0.02	0.12	5.2	12.1	1.4
Perylene	c	c	1.3	2.9	c
o-Phenylenepyrene	c	c	3.8	7.2	0.5
Benzo[ghi]perylene	c	c	5.2	7.8	1.3
Anthanthrene	c	c	1.2	3.2	0.3
Coronene	c	c	5.9	6.3	0.5
Dibenzopyrene	c	c	0.9	1.5	0.3

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[a] Detectable.

[b] Isomer not determined.

[c] Not detected.

SECTION 4

TOXIC AIR POLLUTANTS EMISSION FACTORS

Little information exists on toxic air pollutant emission factors from the iron and steel industry exists. A limited amount of emission factor information for POM compounds, BSO, and benzo(a)pyrene (BaP) is available.[3] Table 6 lists BSO emission factors for poorly controlled coke oven sources.[3] Table 7 shows POM emission factors for coke oven door leaks.[3] Table 8 gives emission test information for coke oven topside leaks for both BSO and BaP.[3]

The majority of the information that is available on emission factors for toxic air pollutants released during iron and steel production can be found in Toxic Air Pollutant Emission Factors - A Compilation for Selected Air Toxic Compounds and Sources.[11] Toxic air pollutant emission factors for a variety of compounds and elements for the major processes identified in the criteria air pollutant section above are listed in this publication. The toxic air pollutant emission factors pertaining to the various processes involved in iron and steel production are included in Table 9. Because of the extensive number of compounds produced and consequent amount of information on emission factors, toxic air pollutant emission factors for coal, natural gas and fuel oil combustion are not included in this table. The reader is referred to reference 11 for information on these emission factors.

Virtually no information is available concerning ratings for toxic air pollutant emission factors. Without having extensive knowledge of the data used to develop the emission factors listed in Table 9, only rough estimates can be made for emission factor ratings. In general, we feel that the emission factors given in Table 9 would be rated D or E since the emission factors listed often are based on a limited number of tests, engineering judgement or were estimated based on elemental or compound content and a criteria pollutant emission factor.

Another reference that can be used in the estimation of toxic air pollutants is the Air Emissions Species Manual[12]. Species profiles are defined for processes in the iron and steel industry. The profiles are multiplied with criteria air pollution estimates to estimate quantities of individual chemical species. Both the VOC and TSP species profiles were developed from test data for one facility in the south coast air basin.

RECOMMENDATIONS

Given the limited amount of information available on toxic air pollutant emission factors from iron and steel production, we recommend that the emission factors in Toxic Air Pollutant Emission Factors - A Compilation for Selected Air Toxic Compounds and Sources be utilized despite the limitations inherent in this compilation.

Table 6. BSO Emission Factors for Poorly Controlled Coke Oven Sources

Source	BSO (kg/Mg of coal)	BSO emission rate
Charging[a]	0.05[9] to 0.55[10,11]	0.2 to 1.5 kg/min of emissions
Doors[b]	0.13 to 0.25[10,11,12]	0.2 to 0.7 kg/hr per leaking door[10,12]
Lids[c]	0.002 to 0.03	0.0033 to 0.021 kg/hr per leaking lid[13]
Offtakes[c]	0.002 to 0.02	0.0033 to 0.021 kg/hr per leaking offtake[13]

[a] For 3 to 5 minutes of uncontrolled emissions.

[b] For 30 to 75 percent leaking doors.

[c] For 20 to 40 percent leaking lids or offtakes.

Table 7. POM Pollutants From Coke Oven Door Leaks (cokeside door only)

POM species	Emission rate (mg/hr)
Naphthalene	387
Fluoranthrene	428
Pyrene	184
Benz(c)phenanthrene	17
Chrysene	124
Benz(a)anthracene	114
7,12-Dimethylbenz(a)anthracene	1
Benz fluoranthrenes	154
Benz(a)pyrene	43
Benz(e)pyrene	95
Cholanthrene	<0.04
Indeno (1,2,3-cd)pyrene	46
Dibenz(a,h)anthracene	48
Dibenz acridines	<0.04
Dibenz(c,g)carbazole	<0.04
Dibenz pyrenes	43
3-Methyl cholanthrene	<0.04

Table 8. Topside Leak Emission Test

Leak size[a]	BSO (kg/hr)	BaP (kg/hr)
Large	0.002[b]	--
	0.017	--
	0.035	--
	0.012	0.00022[c]
Average	0.021	--
Small	0.0017	--
	0.0029	--
	0.0053	0.000072[c]
Average	0.0033	--

[a] A large leak yields a 1- to 2-meter (3- to 6-foot) visible plume. A small leak yields a 0.3-meter (1-foot) visible plume.

[b] Experimental run: vent was partially plugged and flow was restricted.

[c] These values are 1.4 to 1.8 percent of the BSO.

Table 9. Summary of Toxic Air Pollutant Emission Factors for the Iron and Steel Industy

INDUSTRIAL PROCESS	SIC CODE	EMISSION SOURCE	SCC	POLLUTANT	CAS NUMBER	EMISSION FACTOR	NOTES
Coke by-product plants		Entire process		Naphthalene	91203	0.00592 kg/Mg coke	Estimated from capacity and wt. percent naphthalene (8.8)
Coke by-product plants	4925	Cooling tower, direct water	303003	Benzene	71432	270 g/Mg coke produced	Uncontrolled, based on information in BID for Benzene Emis. from Coke By-product Recovery Plants
Coke by-product plants	4925	Cooling tower, direct water	303003	Benzene	71432	51 g/Mg coke produced	Controlled, use tar bottom final cooler, 81% control efficiency
Coke by-product plants	4925	Cooling tower, direct water	303003	Benzene	71432	Negligible	Use wash oil final cooler, 100% efficiency
Coke by-product plants	4925	Cooling tower, tar bottom	303003	Benzene	71432	70 g/Mg coke produced	Uncontrolled
Coke by-product plants	4925	Cooling tower, tar bottom	303003	Benzene	71432	Negligible	Use wash oil final cooler, 100% efficiency
Coke by-product plants	4925	Light-oil condenser vent	303003	Benzene	71432	89 g/Mg coke produced	Uncontrolled
Coke by-product plants	4925	Light-oil condenser vent	303003	Benzene	71432	1.8 g/Mg coke produced	Coke oven gas blanketing from gas holder, 98% efficiency
Coke by-product plants	4925	Naphthalene separation	303003	Benzene	71432	87 g/Mg coke produced	Uncontrolled
Coke by-product plants	4925	Naphthalene processing	303003	Benzene	71432	20 g/Mg coke produced	Uncontrolled
Coke by-product plants	4925	Tar-intercepting sump	303003	Benzene	71432	95 g/Mg coke produced	Uncontrolled
Coke by-product plants	4925	Tar-intercepting sump	303003	Benzene	71432	1.9 g/Mg coke produced	Controlled, coke oven gas blanketing from collecting main, 98% efficiency
Coke by-product plants	4925	Tar dewatering	303003	Benzene	71432	21 g/Mg coke produced	Uncontrolled
Coke by-product plants	4925	Tar dewatering	303003	Benzene	71432	2.1 g/Mg coke produced	Controlled, wash oil scrubber, 90% efficiency
Coke by-product plants	4925	Tar dewatering	303003	Benzene	71432	0.42 g/Mg coke produced	Controlled, coke oven gas blanketing from collecting main, 98% efficiency
Coke by-product plants	4925	Tar decanter	303003	Benzene	71432	77 g/Mg coke produced	Uncontrolled
Coke by-product plants	4925	Tar decanter	303003	Benzene	71432	3.9 g/Mg coke produced	Controlled, coke oven gas blanketing from collecting main, 95% efficiency
Coke by-product plants	4925	Tar storage	303003	Benzene	71432	12 g/Mg coke produced	Uncontrolled
Coke by-product plants	4925	Tar storage	303003	Benzene	71432	0.24 g/Mg coke produced	Controlled, coke oven gas blanketing from collecting oven, 98% efficiency
Coke by-product plants	4925	Tar storage	303003	Benzene	71432	1.2 g/Mg coke produced	Controlled, wash-oil scrubber, 90% efficiency
Coke by-product plants	4925	Light-oil sump	303003	Benzene	71432	15 g/Mg coke produced	Uncontrolled

Table 9. (continued)

INDUSTRIAL PROCESS	SIC CODE	EMISSION SOURCE	SCC	POLLUTANT	CAS NUMBER	EMISSION FACTOR	NOTES
Coke by-product plants	4925	Light-oil sump	303003	Benzene	71432	0.3 g/Mg coke produced	Controlled, source enclosure, 98% efficiency
Coke by-product plants	4925	Light-oil storage	303003	Benzene	71432	5.8 g/Mg coke produced	Uncontrolled
Coke by-product plants	4925	Light-oil storage	303003	Benzene	71432	0.12 g/Mg coke produced	Controlled, coke oven gas blanketing from gas holder, 98% efficiency
Coke by-product plants	4925	Light-oil storage	303003	Benzene	71432	0.58 g/Mg coke produced	Wash-oil scrubber, 90% efficiency
Coke by-product plants	4925	BTX storage	303003	Benzene	71432	5.8 g/Mg coke produced	Uncontrolled
Coke by-product plants	4925	BTX storage	303003	Benzene	71432	0.12 g/Mg coke produced	Coke oven gas blanketing from gas holder, 98% efficiency
Coke by-product plants	4925	BTX storage	303003	Benzene	71432	0.58 g/Mg coke produced	Wash-oil scrubber, 90% efficiency
Coke by-product plants	4925	Benzene storage	303003	Benzene	71432	5.8 g/Mg coke produced	Uncontrolled
Coke by-product plants	4925	Benzene storage	303003	Benzene	71432	0.12 g/Mg coke produced	Controlled, nitrogen or natural gas blanketing system, 98% efficiency
Coke by-product plants	4925	Benzene storage	303003	Benzene	71432	0.58 g/Mg coke produced	Wash-oil scrubber, 90% efficiency
Coke by-product plants	4925	Flushing-liquor circulation tank	303003	Benzene	71432	9 g/Mg coke produced	Uncontrolled
Coke by-product plants	4925	Flushing-liquor circulation tank	303003	Benzene	71432	0.18 g/Mg coke produced	Coke oven gas blanketing from collecting main, 98% efficiency
Coke by-product plants	4925	Excess-ammonia liquor tank	303003	Benzene	71432	9 g/Mg coke produced	Uncontrolled
Coke by-product plants	4925	Excess-ammonia liquor tank	303003	Benzene	71432	0.18 g/Mg coke produced	Coke oven gas blanketing from collecting main, 98% efficiency
Coke by-product plants	4925	Wash-oil decanter	303003	Benzene	71432	3.8 g/Mg coke produced	Uncontrolled
Coke by-product plants	4925	Wash-oil decanter	303003	Benzene	71432	0.076 g/Mg coke produced	Controlled, 98% efficiency, coke oven gas blanketing from gas holder
Coke by-product plants	4925	Wash-oil circulation tank	303003	Benzene	71432	3.8 g/Mg coke produced	Uncontrolled
Coke by-product plants	4925	Wash-oil circulation tank	303003	Benzene	71432	0.76 g/Mg coke produced	Controlled, 98% efficiency, coke oven gas blanketing from gas holder
Coke by-product recovery	3312	Tar processing - decanter	30300315	POM		4.1 g/Mg coal fed to coking oven	Uncontrolled, represents both gaseous and particulate POM
Coke by-product recovery	3312	Tar processing - dewatering and storage	30300315	POM		0.003 g/Mg coal fed to coking ovens	Uncontrolled, represents both gaseous and particulate POM
Coke by-product recovery	3312	Tar processing - distillation product storage	30300315	POM		0.011 g/Mg coal fed to coking ovens	Uncontrolled, represents both gaseous and particulate POM
Coke manufacture	3312	Coke oven	303003	Toluene	108883	2.4 x 10E-4 lb/lb coke produced	
Coke manufacture	3312	Wet coal charging larry car	30300302	Ammonia	7664417	0.02 lb/ton coal charged	Uncontrolled
Coke manufacture	3312	Coke pushing	30300303	Ammonia	7664417	0.1 lb/ton coal charged	Uncontrolled
Coke manufacture	3312	Door leaks	30300308	Ammonia	7664417	0.06 lb/ton coal charged	Uncontrolled
Coke oven ammonium sulfate production	3312	Rotary dryer	303003	Ammonium sulfate	7783202	10 kg/Mg ammonium sulfate produced	Uncontrolled
Coke oven gas boiler	4925	Emission stream	10200802	Benzene	71432	0.42% by vol (1.90% by wt)	South Coast study, California, engineering judgement

Table 9. (continued)

INDUSTRIAL PROCESS	SIC CODE	EMISSION SOURCE	SCC	POLLUTANT	CAS NUMBER	EMISSION FACTOR	NOTES
Coking	3312	Coke oven battery	303003	Manganese	7439965	0.000013 lb/lb coal burned	Based on engineering estimates
Coking	3312	Charging	30300302	Coke oven emissions		0.05 to 0.55 kg/Mg coal	For 3-5 mins. uncontrolled charging
Coking	3312	Coke quenching	30300304	POM		1.85 g/Mg coal charged	Clean water quench
Coking	3312	Coke quenching	30300304	POM		613 g/Mg coal charged	Contaminated water used for quench
Coking	3312	Coke quenching	30300304	Benzo(a)pyrene	50328	0.0005 g/Mg coal charged	
Coking	3312	Door leaks	30300308	POM		5524 ng/Nm3	Uncontrolled, average of 4 test runs
Coking	3312	Door leaks	30300308	POM		1256 ng/Nm3	Wet ESP
Coking	3312	Door leaks	30300308	POM		0.00007 g/Mg coal charged	Wet ESP
Coking	3312	Doors	30300308	Coke oven emissions		0.13 to 0.25 kg/Mg coal	For 30 to 75% leaking doors
Coking	3312	Door leaks	30300308	Benzo(a)pyrene	50328	141 ng/Nm3	Uncontrolled
Coking	3312	Door leaks	30300308	Benzo(a)pyrene	50328	1.8 ng/Nm3	Wet ESP
Coking	3312	Lids	30300314	Coke oven emissions		0.002-0.03 kg/Mg coal	For 20 to 40% leaking lids
Iron and steel foundry	332	Green sand shakeout	304	Cadmium	7440439	1.326 mg/ton metal cast	Uncontrolled, Cd dust less than 3 um size only
Iron and steel production	3312	General	303	Manganese	7439965	0.00002 lb/lb iron and steel produced	Based on engineering estimates
Iron and steel production	3312	Sintering operations, sinter discharge (breaker and hot screen)	303008	Manganese	7439965	0.08 lb/ton of sinter	Uncontrolled, calculated based on engineering judgement
Iron and steel production	3312	Sintering operations, sinter discharge (breaker and hot screen)	303008	Manganese	7439965	0.0012 lb/ton of sinter	Controlled by fabric filter, calculated based on engineering judgement
Iron and steel production	3312	Sintering operations, sinter discharge (breaker and hot screen)	303008	Manganese	7439965	0.007 lb/ton of sinter	Controlled by orifice scrubber, calculated based on engineering judgement
Iron and steel production	3312	Sintering operations, windbox and discharge	303008	Manganese	7439965	0.0036 lb/ton of sinter	Controlled by fabric filter, calculated based on engineering judgement
Iron and steel production	3312	Blast furnace	303008	Vanadium	7440622	1.4 lb/thousand tons pig iron produced	Control status/basis unclear
Iron and steel production	3312	Sintering operations, windbox exhaust	30300813	Manganese	7439965	0.134 lb/ton of sinter	Uncontrolled, calculated based on engineering judgement
Iron and steel production	3312	Sintering operations, windbox exhaust	30300813	Manganese	7439965	0.104 lb/ton of sinter	After coarse particle removal, calculated based on engineering judgement
Iron and steel production	3312	Sintering operations, windbox exhaust	30300813	Manganese	7439965	0.0192 lb/ton of sinter	Controlled by dry ESP, calculated based on engineering judgement
Iron and steel production	3312	Sintering operations, windbox exhaust	30300813	Manganese	7439965	0.002 lb/ton of sinter	Controlled by wet ESP, calculated based on engineering judgement

Table 9. (continued)

INDUSTRIAL PROCESS	SIC CODE	EMISSION SOURCE	SCC	POLLUTANT	CAS NUMBER	EMISSION FACTOR	NOTES
Iron and steel production	3312	Sintering operations, windbox exhaust	30300813	Manganese	7439965	0.0056 lb/ton of sinter	Controlled by scrubber, calculated based on engineering judgement
Iron and steel production	3312	Sintering operations, windbox exhaust	30300813	Manganese	7439965	0.012 lb/ton of sinter	Controlled by cyclone, calculated based on engineering judgement
Iron and steel production	3312	Sinter plants/windbox	30300813	Copper	7440508	0.004 kg/Mg finished sinter	Uncontrolled, after coarse PM removal, copper content 0.104%
Iron and steel production	3312	Sinter plants/windbox	30300813	Copper	7440508	0.00009 kg/Mg finished sinter	Wet ESP, copper content 0.104%
Iron and steel production	3312	Sinter plants/sinter discharge	30300814	Copper	7440508	0.003 kg/Mg finished sinter	Uncontrolled, copper content 0.104%
Iron and steel production	3312	Sinter plants/sinter discharge	30300814	Copper	7440508	0.00005 kg/Mg finished sinter	Baghouse, copper content 0.104%
Iron and steel production	3312	Blast furnace	30300822	Copper	7440508	0.001 kg/Mg hot metal	Uncontrolled, average copper content 0.25, range 0.051-0.5%
Iron and steel production	3312	Iron blast furnaces, casthouse emissions	30300825	Manganese	7439965	0.0018 lb/ton of iron	Uncontrolled, calculated based on engineering judgement
Iron and steel production	3312	Iron blast furnaces, casthouse emissions	30300825	Manganese	7439965	0.00018 lb/ton of iron	Controlled by runner covers & pickup hoods to fabric filter, calculated based on engineering judge.
Iron and steel production	3312	Iron blast furnaces, slips	30300826	Manganese	7439965	0.261 lb/slip	Uncontrolled, calculated based on engineering judgement
Iron and steel production	3312	Open hearth furnace operations, roof monitor	303009	Manganese	7439965	0.0006 lb/ton of pig iron	Uncontrolled, calculated based on engineering judgement
Iron and steel production	3312	Open hearth furnace operations, teeming	303009	Manganese	7439965	0.00026 lb/ton of pig iron	Uncontrolled, calculated based on engineering judgement
Iron and steel production	3312	Open hearth furnace operations, teeming	303009	Manganese	7439965	0.000006 lb/ton of pig iron	Controlled by side-draft hood to fabric filter, calculated based on engineering judgement
Iron and steel production	3312	Basic oxygen furnace (melting/refining)	303009	Copper	7440508	0.005 kg/Mg steel produced	Uncontrolled, copper content 0.035%
Iron and steel production	3312	Basic oxygen furnace (melting/refining)	303009	Copper	7440508	0.00002 kg/Mg steel produced	Open hood, vented to ESP
Iron and steel production	3312	Open hearth furnace operations, melting/refining	30300901	Manganese	7439965	0.078 lb/ton of pig iron	Uncontrolled, calculated based on engineering judgement
Iron and steel production	3312	Open hearth furnace operations, melting/refining	30300901	Manganese	7439965	0.001 lb/ton of pig iron	Controlled by ESP, calculated based on engineering judgement
Iron and steel production	3312	Open hearth furnace - melting/refining	30300901	Copper	7440508	0.02 kg/Mg steel	Uncontrolled, copper content 0.16%
Iron and steel production	3312	Open hearth furnace - melting/refining	30300901	Copper	7440508	0.0002 kg/Mg steel	Controlled - ESP, copper content 0.16
Iron and steel production	3312	Electric arc furnace - charging/tapping/slagging	30300906	Copper	7440508	0.002 kg/Mg steel	Uncontrolled, copper content 0.265%, carbon steel
Iron and steel production	3312	Electric arc furnace - melting/refining	30300908	Copper	7440508	0.05 kg/Mg steel produced	Uncontrolled, copper content 0.265%, carbon steel
Iron and steel production	3312	Basic oxygen furnace charging	30300916	Copper	7440508	0.0001 kg/Mg hot metal	At source, copper content 0.035%
Iron and steel production	3312	Basic oxygen furnace tapping	30300917	Copper	7440508	0.0002 kg/Mg steel	At source, copper content 0.035%

Table 9. (continued)

INDUSTRIAL PROCESS	SIC CODE	EMISSION SOURCE	SCC	POLLUTANT	CAS NUMBER	EMISSION FACTOR	NOTES
Secondary iron and steel production	332	Sinter windbox	304	Cadmium	7440439	2 x 10E-3 lb/ton feed	Uncontrolled
Secondary iron and steel production	332	Sinter windbox	304	Cadmium	7440439	9.5 x 10E-4 lb/ton feed	Controlled with rotoclone and ESP
Secondary iron and steel production	332	Open hearth	304	Cadmium	7440439	5.78 x 10E-3 lb/ton steel	Uncontrolled, stack sampling
Secondary iron and steel production	332	Open hearth	304	Cadmium	7440439	1.1 x 10E-4 lb/ton steel	Controlled with ESP, stack sampling
Secondary iron and steel production	332	Basic oxygen furnace	304	Cadmium	7440439	4.1 x 10E-5 lb/ton steel	Uncontrolled, based on Cd content in feed, fuel, or emissions
Secondary iron and steel production	332	Basic oxygen furnace	304	Cadmium	7440439	2.79 x 10E-5 lb/ton steel	Controlled with venturi scrubber or ESP
Secondary iron and steel production	332	Electric arc furnace	304	Cadmium	7440439	3.4 x 10E-3 lb/ton steel	Engineering estimate, stack test, concentration of Cd in fuel, feed, or emissions
Steel foundries	332	Electric arc furnace	30400701	Manganese	7439965	0.52 lb/ton of iron	Uncontrolled, calculated based on engineering judgement
Steel foundries	332	Electric arc furnace	30400701	Manganese	7439965	0.026 lb/ton of iron	Controlled by ESP, calculated based on engineering judgement
Steel foundries	332	Electric arc furnace	30400701	Manganese	7439965	0.013 lb/ton of iron	Controlled by venturi scrubber, calculated based on engineering judgement
Steel foundries	332	Electric arc furnace	30400701	Manganese	7439965	0.0008 lb/ton of iron	Controlled by fabric filter, calculated based on engineering judgement
Steel foundries	332	Induction furnace	30400705	Manganese	7439965	0.004 lb/ton of iron	Uncontrolled, calculated based on engineering judgement
Steel mill	331	Open hearth furnace	303009	Cadmium	7440439	0.00014 kg/metric ton produced	Uncontrolled, calculated from data presented in the reference
Steel mill	331	Open hearth furnace	303009	Cadmium	7440439	2.2 x 10E-6 kg/metric ton produced	Controlled with ESP, calculated from data presented in the reference
Steel pickling	3312	Absorber towers	30300910	Hydrogen chloride	7647010	0.00055-0.0011 lbs/ton steel pickled	Calculated from information in reference
Steel production	3312	Basic oxygen furnace operations, Q-BOP process melting/refining	303009	Manganese	7439965	0.00056 lb/ton of steel	Controlled by scrubber, calculated based on engineering judgement
Steel production	3312	Basic oxygen furnace operations, BOF monitor	303009	Manganese	7439965	0.005 lb/ton of steel	All sources, uncontrolled, calculated based on engineering judgement

Table 9. (continued)

INDUSTRIAL PROCESS	SIC CODE	EMISSION SOURCE	SCC	POLLUTANT	CAS NUMBER	EMISSION FACTOR	NOTES
Steel production	3312	Electric arc furnace operations, charging/tapping/slagging	303009	Manganese	7439965	0.049 lb/ton of product	Uncontrolled at roof monitor, calculated based on engineering judgement
Steel production	3312	Electric arc furnace operations, melt/refine/charge/tap/slag carbon steel	303009	Manganese	7439965	1.75 lb/ton of product	Uncontrolled, calculated based on engineering judgement
Steel production	3312	Electric arc furnace operations, melt/refine/charge/tap/slag carbon steel	303009	Manganese	7439965	0.0015 lb/ton of product	Controlled by DEC plus charging hood to fabric filter, calculated based on engineering judgement
Steel production	3312	Electric arc furnace operations, melt/refine/charge/tap/slag alloy steel	303009	Manganese	7439965	0.656 lb/ton of product	Uncontrolled, calculated based on engineering judgement
Steel production	3312	Electric arc furnace operations, melt/refine/charge/tap/slag alloy steel	303009	Manganese	7439965	0.0174 lb/ton of product	Controlled by total building evacuation to fabric filter, calculated based on engineering judgement
Steel production	3312	Open hearth fugitive emissions	303009	Nickel	7440020	0.00005 lb/ton of steel produced	Uncontrolled, calculated based on source tests
Steel production	3312	Basic oxygen process fugitives	303009	Nickel	7440020	0.0001 lb/ton of steel produced	Uncontrolled, calculated based on source tests
Steel production	3312	Electric arc furnace fugitive emissions (carbon steel)	303009	Nickel	7440020	0.00054 lb/ton of steel produced	Uncontrolled, calculated based on source tests
Steel production	3312	Electric arc furnace fugitive emissions (carbon steel)	303009	Nickel	7440020	0.00011 lb/ton of steel produced	Controlled with hoods and fabric filter, calculated based on source tests
Steel production	3312	Electric arc furnace fugitive emissions (alloy steel)	303009	Nickel	7440020	0.0016 lb/ton of steel produced	Uncontrolled, calculated based on source tests
Steel production	3312	Electric arc furnace fugitive emissions (alloy steel)	303009	Nickel	7440020	0.00032 lb/ton of steel produced	Controlled with hoods and fabric filter, calculated based on source tests
Steel production	3312	Argon-oxygen decarburization vessel: stainless and specialty alloys	303009	Chromium	7440473	0.53 kg/Mg steel produced	Average of 0.43-0.62, as total chromium, after capture, before control
Steel production	3312	Basic oxygen furnace	303009	Vanadium	7440622	0.3 lb/thousand tons steel produced	97% emission control, based on particulate emission factor and V content
Steel production	3312	Open hearth furnace	303009	Zinc	7440666	1.3 lb/ton steel produced	Based on controlled particulate emis. factor of 10.2 lb/ton steel produced, w/ zinc content of 12.5%
Steel production	3312	Basic oxygen furnace	303009	Zinc	7440666	0.3 lb/ton steel produced	Based on controlled particulate emis. factor of 14 lb/ton steel produced & zinc content of 2.24%
Steel production	3312	Electric arc furnace	303009	Zinc	7440666	0.7 lb/ton steel produced	Based on controlled particulate emis. factor of 2.5 lb/ton steel prod. & part. zinc content of 29.6%
Steel production	3312	Open hearth furnace	30300901	Nickel	7440020	0.00018 lb/ton of steel produced	Controlled by ESP, calculated based on source tests

Table 9. (continued)

INDUSTRIAL PROCESS	SIC CODE	EMISSION SOURCE	SCC	POLLUTANT	CAS NUMBER	EMISSION FACTOR	NOTES
Steel production	3312	Open hearth furnace	30300901	Vanadium	7440622	5.1 lb/thousand tons steel produced	40% control efficiency, based on particulate emission factor and V content
Steel production	3312	Electric arc furnace (alloy steel)	30300904	Nickel	7440020	0.025 lb/ton of steel produced	Uncontrolled, calculated based on source tests
Steel production	3312	Electric arc furnace (alloy steel)	30300904	Nickel	7440020	0.000039-0.00025 lb/ton steel produced	Controlled with fabric filter, calculated based on source tests
Steel production	3312	Electric arc furnace: stainless and specialty	30300904	Chromium	7440473	1.6 kg/Mg steel produced	Average of 0.8-2.4, total chromium, after capture, before control
Steel production	3312	Electric arc furnace: mixed products	30300904	Chromium	7440473	0.34 kg/Mg steel produced	Average of 0.17-0.5, total chromium, after capture, before control
Steel production	3312	Electric arc furnace	30300904	Vanadium	7440622	0.008 lb/ton of steel produced	78% emission control, based on particulate emission factor and V content
Steel production	3312	Electric arc furnace operations, melting/refining carbon steel	30300908	Manganese	7439965	1.33 lb/ton of product	Uncontrolled, calculated based on engineering judgement
Steel production	3312	Electric arc furnace (carbon steel)	30300908	Nickel	7440020	0.0083 lb/ton of steel produced	Uncontrolled, calculated based on source tests
Steel production	3312	Electric arc furnace (carbon steel)	30300908	Nickel	7440020	0.000013-0.000084 lb/ton steel produced	Controlled by fabric filter, calculated based on source tests
Steel production	3312	Electric arc furnace: carbon and alloy steel	30300908	Chromium	7440473	0.03 kg/Mg steel produced	Average of 0.015-0.045, as total chromium, after capture, before control
Steel production	3312	Top-blown basic oxygen furnace, melting/refining	30300913	Manganese	7439965	0.285 lb/ton of steel	Uncontrolled, calculated based on engineering judgement
Steel production	3312	Top-blown basic oxygen furnace, melting/refining	30300913	Manganese	7439965	0.013 lb/ton of steel	Controlled by open hood vented to ESP, calculated based on engineering judgement
Steel production	3312	Top-blown basic oxygen furnace, melting/refining	30300913	Manganese	7439965	0.009 lb/ton of steel	Controlled by open hood vented to scrubber, calculated based on engineering judgement
Steel production	3312	Basic oxygen process furnace	30300913	Nickel	7440020	0.000018 lb/ton of steel produced	Controlled by scrubber, calculated based on source tests
Steel production	3312	Top-blown basic oxygen furnace, melting/refining	30300914	Manganese	7439965	0.00068 lb/ton of steel	Controlled by closed hood vented to scrubber, calculated based on engineering judgement
Steel production	3312	Basic oxygen process furnace	30300914	Nickel	7440020	0.000018 lb/ton of steel produced	Controlled by scrubber, calculated based on source tests
Steel production	3312	Basic oxygen furnace operations, hot metal transfer	30300915	Manganese	7439965	0.0004 lb/ton of steel	At source, uncontrolled, calculated based on engineering judgement
Steel production	3312	Basic oxygen furnace operations, charging	30300916	Manganese	7439965	0.006 lb/ton of steel	At source, uncontrolled, calculated based on engineering judgement

Table 9. (continued)

INDUSTRIAL PROCESS	SIC CODE	EMISSION SOURCE	SCC	POLLUTANT	CAS NUMBER	EMISSION FACTOR	NOTES
Steel production	3312	Basic oxygen furnace operations, tapping	30300917	Manganese	7439965	0.0092 lb/ton of steel	At source, uncontrolled, calculated based on engineering judgement
Steel production	3312	Zinc galvanizing kettles	30300936	Zinc	7440666	0.0018 Mg/Mg zinc processed	Based on emissions data obtained from galvanizing plants in the late 1960s
Steel production	3312	Electric arc furnace (stainless steel)	30300998	Nickel	7440020	0.3 lb/ton of steel produced	Uncontrolled, calculated based on source tests
Steel production	3312	Electric arc furnace (stainless steel)	30300998	Nickel	7440020	0.003 lb/ton of steel produced	Controlled with fabric filter, calculated based on source tests
Steel production	3312	Electric arc furnace fugitive emissions (stainless steel)	30300998	Nickel	7440020	0.036 lb/ton of steel produced	Uncontrolled, calculated based on source tests
Steel production	3312	Electric arc furnace fugitive emissions (stainless steel)	30300998	Nickel	7440020	0.0072 lb/ton of steel produced	Controlled with hoods and fabric filter, calculated based on source tests

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12. Air Emissions Species Manual. Volume 1: Volatile Organic Compound Species Profiles and Volume 2: Particulate Matter Species Profiles, EPA-450/2-88-003a and 003b, (NTIS PB88-225792 and -225800), U.S. Environmental Protection Agency, Research Triangle Park, NC, April, 1988.

APPENDIX A

Excerpts From AP-42 Pertinent to Iron and Steel Making Criteria and Toxic Pollutants

AP-42 Section

1.1 Bituminous and Subbituminous Coal Combustion A-2
1.2 Anthracite Coal Combustion A-19
1.3 Fuel Oil Combustion A-26
1.4 Natural Gas Combustion A-37
6.18 Ammonium Sulfate Manufacture A-43
7.2 Coke Manufacturing A-47
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11.2.1 Unpaved Roads A-96
11.2.3 Aggregate Handling and Storage Piles A-104
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1.1 BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION

1.1.1 General[1]

Coal is a complex combination of organic matter and inorganic ash formed over eons from successive layers of fallen vegetation. Coal types are broadly classified as anthracite, bituminous, subbituminous or lignite, and classification is made by heating values and amounts of fixed carbon, volatile matter, ash, sulfur and moisture. Formulas for differentiating coals based on these properties are given in Reference 1. See Sections 1.2 and 1.7 for discussions of anthracite and lignite, respectively.

There are two major coal combustion techniques, suspension firing and grate firing. Suspension firing is the primary combustion mechanism in pulverized coal and cyclone systems. Grate firing is the primary mechanism in underfeed and overfeed stokers. Both mechanisms are employed in spreader stokers.

Pulverized coal furnaces are used primarily in utility and large industrial boilers. In these systems, the coal is pulverized in a mill to the consistency of talcum powder (i. e., at least 70 percent of the particles will pass through a 200 mesh sieve). The pulverized coal is generally entrained in primary air before being fed through the burners to the combustion chamber, where it is fired in suspension. Pulverized coal furnaces are classified as either dry or wet bottom, depending on the ash removal technique. Dry bottom furnaces fire coals with high ash fusion temperatures, and dry ash removal techniques are used. In wet bottom (slag tap) furnaces, coals with low ash fusion temperatures are used, and molten ash is drained from the bottom of the furnace. Pulverized coal furnaces are further classified by the firing position of the burners, i. e., single (front or rear) wall, horizontally opposed, vertical, tangential (corner fired), turbo or arch fired.

Cyclone furnaces burn low ash fusion temperature coal crushed to a 4 mesh size. The coal is fed tangentially, with primary air, to a horizontal cylindrical combustion chamber. In this chamber, small coal particles are burned in suspension, while the larger particles are forced against the outer wall. Because of the high temperatures developed in the relatively small furnace volume, and because of the low fusion temperature of the coal ash, much of the ash forms a liquid slag which is drained from the bottom of the furnace through a slag tap opening. Cyclone furnaces are used mostly in utility and large industrial applications.

In spreader stokers, a flipping mechanism throws the coal into the furnace and onto a moving fuel bed. Combustion occurs partly in suspension and partly on the grate. Because of significant carbon in the particulate, flyash reinjection from mechanical collectors is commonly employed to improve boiler efficiency. Ash residue in the fuel bed is deposited in a receiving pit at the end of the grate.

TABLE 1.1-1. EMISSION FACTORS FOR EXTERNAL BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION[a]

Firing Configuration	Particulate[b]		Sulfur Oxides[c]		Nitrogen Oxides[d]		Carbon Monoxide[e]		Nonmethane VOC[e,f]		Methane[e]	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Pulverized coal fired Dry bottom	5A	10A	19.5S(17.5S)	39S(35S)	10.5(7.5)[g]	21(15)[g]	0.3	0.6	0.04	0.07	0.015	0.03
Wet bottom	3.5A[h]	7A[h]	19.5S(17.5S)	39S(35S)	17	34	0.3	0.6	0.04	0.07	0.015	0.03
Cyclone furnace	1A[h]	2A[h]	19.5S(17.5S)	39S(35S)	18.5	37	0.3	0.6	0.04	0.07	0.015	0.03
Spreader stoker Uncontrolled	30[j]	60[j]	19.5S(17.5S)	39S(35S)	7	14	2.5	5	0.04	0.07	0.015	0.03
After multiple cyclone With fly ash reinjection from multiple cyclone	8.5	17	19.5S(17.5S)	39S(35S)	7	14	2.5	5	0.04	0.07	0.015	0.03
No fly ash reinjection from multiple cyclone	6	12	19.5S(17.5S)	39S(35S)	7	14	2.5	5	0.04	0.07	0.015	0.03
Overfeed stoker[k] Uncontrolled	8[m]	16[m]	19.5S(17.5S)	39S(35S)	3.25	7.5	3	6	0.04	0.07	0.015	0.03
After multiple cyclone	4.5[n]	9[n]	19.5S(17.5S)	39S(35S)	3.25	7.5	3	6	0.04	0.07	0.015	0.03
Underfeed stoker Uncontrolled	7.5[p]	15[p]	15.5S	31S	4.75	9.5	5.5	11	0.65	1.3	0.4	0.8
After multiple cyclone	5.5[n]	11[n]	15.5S	31S	4.75	9.5	5.5	11	0.65	1.3	0.4	0.8
Handfired units	7.5	15	15.5S	31S	1.5	3	45	90	5	10	4	8

[a] Factors represent uncontrolled emissions unless otherwise specified and should be applied to coal consumption as fired.

[b] Based on EPA Method 5 (front half catch) as described in Reference 12. Where particulate is expressed in terms of coal ash content, A, factor is determined by multiplying weight % ash content of coal (as fired) by the numerical value preceding the "A". For example, if coal having 8% ash is fired in a dry bottom unit, the particulate emission factor would be 5 x 8, or 40 kg/Mg (80 lb/ton). The "condensible" matter collected in back half catch of EPA Method 5 averages <5% of front half, or "filterable", catch for pulverized coal and cyclone furnaces; 10% for spreader stokers; 15% for other stokers; and 50% for handfired units (References 6, 19, 49).

[c] Expressed as SO_2, including SO_2, SO_3 and gaseous sulfates. Factors in parentheses should be used to estimate gaseous SO_x emissions for subbituminous coal. In all cases, "S" is weight % sulfur content of coal as fired. See Footnote b for example calculation. On average for bituminous coal, 97% of fuel sulfur is emitted as SO_2, and only about 0.7% of fuel sulfur is emitted as SO_3 and gaseous sulfate. An equally small percent of fuel sulfur is emitted as particulate sulfate (References 9, 13). Small quantities of sulfur are also retained in bottom ash. With subbituminous coal generally about 10% more fuel sulfur is retained in the bottom ash and particulate because of the more alkaline nature of the coal ash. Conversion to gaseous sulfate appears about the same as for bituminous coal.

[d] Expressed as NO_2. Generally, 95 - 99 volume % of nitrogen oxides present in combustion exhaust will be in the form of NO, the rest NO_2 (Reference 11). To express factors as NO, multiply by factor of 0.66. All factors represent emission at baseline operation (i.e., 60 - 110% load and no NO_x control measures, as discussed in text).

[e] Nominal values achieveable under normal operating conditions. Values one or two orders of magnitude higher can occur when combustion is not complete.

[f] Nonmethane volatile organic compounds (VOC), expressed as C_2 to C_{16} n-alkane equivalents (Reference 58). Because of limited data on NMVOC available to distinguish the effects of firing configuration, all data were averaged collectively to develop a single average for pulverized coal units, cyclones, spreaders and overfeed stokers.

[g] Parenthetic value is for tangentially fired boilers.

[h] Uncontrolled particulate emissions, when no fly ash reinjection is employed. When control device is installed, and collected fly ash is reinjected to boiler, particulate from boiler reaching control equipment can increase by up to a factor of two.

[j] Accounts for fly ash settling in an economizer, air heater or breeching upstream of control device or stack. (Particulate directly at boiler outlet typically will be twice this level.) Factor should be applied even when fly ash is reinjected to boiler from boiler, air heater or economizer dust hoppers.

[k] Includes traveling grate, vibrating grate and chain grate stokers.

[m] Accounts for fly ash settling in breeching or stack base. Particulate loadings directly at boiler outlet typically can be 50% higher.

[n] See text for discussion of apparently low multiple cyclone control efficiencies, regarding uncontrolled emissions.

[p] Accounts for fly ash settling in breeching downstream of boiler outlet.

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TABLE 1.1-2. EMISSION FACTOR RATINGS[*] AND REFERENCES FOR BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION

Firing Configuration	Particulate		Sulfur Oxides		Nitrogen Oxides		Carbon Monoxide		Nonmethane VOC		Methane	
	Rating	Ref.	Rating	Ref.	Rating	Ref.	Rating	Ref.	Rating	Ref.	Rating	Ref.
Pulverized coal fired												
Dry bottom	A	14-25	A	9,16-19,21, 31-37,39, 41-46,51-55	A	11,14,16-17, 21,46,56	A	16,18-19,21 47,57	A	55,58	A	58
Wet bottom	D	14,16,26	A	"	C	14,16	A	"	A	58	A	"
Cyclone furnace	D	14,19,22, 27-29	A	"	B	11	A	"	A	"	A	"
Spreader stoker												
Uncontrolled	B	17,30-35	A	"	A	11,17,31-37 39-40,46	A	17,19,31-34, 36,47,51	A	"	A	"
After multiple cyclone												
With flyash reinjection from cyclone	B	14,32,36-38	A	"	A	"	A	"	A	"	A	"
No flyash reinjection from cyclone	A	17,31-35, 39,40,59	A	"	A	"	A	"	A	"	A	"
Overfeed stoker												
Uncontrolled	B	6,17,41-43, 45-47	A	"	A	11,17,19, 41-45	B	17,41-42,45, 47,51	A	"	A	"
After multiple cyclone	B	6,41,44-45	A	"	A	"	B	"	A	"	A	"
Underfeed stoker												
Uncontrolled	B	6,19,47-48	B	19,48	B	19,47-48	B	19,47-48	A	47,58	A	47,58
After multiple cyclone	C	6	B	"	B	"	B	"	A	"	A	"
Handfired units	D	49-50	D	"	D	50	D	50	D	50,58	D	50,58

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[*] These ratings, in the context of this Section, refer to the number of test data on which each emission factor is based. An "A" rating means the factor is based on tests at ten or more boilers, a "B" rating on six to nine test data, and a "C" rating on test data for two to five boilers. A "D" rating indicates the factor is based on only a single datum or extrapolated from a secondary reference. These ratings are not a measure of the scatter in the underlying test data. However, a higher rating will generally increase confidence that a given factor will better approximate the average emissions for a particular boiler category.

In overfeed stokers, coal is fed onto a traveling or vibrating grate, and it burns on the fuel bed as it progresses through the furnace. Ash particles fall into an ash pit at the rear of the stoker. The term "overfeed" applies because the coal is fed onto the moving grate under an adjustable gate. Conversely, in "underfeed" stokers, coal is fed into the firing zone from underneath by mechanical rams or screw conveyers. The coal moves in a channel, known as a retort, from which it is forced upward, spilling over the top of each side to form and to feed the fuel bed. Combustion is completed by the time the bed reaches the side dump grates from which the ash is discharged to shallow pits. Underfeed stokers include single retort units and multiple retort units, the latter having several retorts side by side.

1.1.2 Emissions And Controls

The major pollutants of concern from external coal combustion are particulate, sulfur oxides and nitrogen oxides. Some unburnt combustibles, including numerous organic compounds and carbon monoxide, are generally emitted even under proper boiler operating conditions.

Particulate[2-4] - Particulate composition and emission levels are a complex function of firing configuration, boiler operation and coal properties. In pulverized coal systems, combustion is almost complete, and thus particulate largely comprises inorganic ash residue. In wet bottom pulverized coal units and cyclones, the quantity of ash leaving the boiler is less than in dry bottom units, since some of the ash liquifies, collects on the furnace walls, and drains from the furnace bottom as molten slag. To increase the fraction of ash drawn off as wet slag, and thus to reduce the flyash disposal problem, flyash may be reinjected from collection equipment into slag tap systems. Dry bottom unit ash may also be reinjected into wet bottom boilers for the same purpose.

Because a mixture of fine and coarse coal particles is fired in spreader stokers, significant unburnt carbon can be present in the particulate. To improve boiler efficiency, flyash from collection devices (typically multiple cyclones) is sometimes reinjected into spreader stoker furnaces. This practice can dramatically increase the particulate loading at the boiler outlet and, to a lesser extent, at the mechanical collector outlet. Flyash can also be reinjected from the boiler, air heater and economizer dust hoppers. Flyash reinjection from these hoppers does not increase particulate loadings nearly so much as from multiple cyclones.[5]

Uncontrolled overfeed and underfeed stokers emit considerably less particulate than do pulverized coal units and spreader stokers, since combustion takes place in a relatively quiescent fuel bed. Flyash reinjection is not practiced in these kinds of stokers.

Other variables than firing configuration and flyash reinjection can affect emissions from stokers. Particulate loadings will often increase as load increases (especially as full load is approached) and with sudden load changes. Similarly, particulate can increase as the ash and fines contents increase. ("Fines", in this context, are coal particles smaller than about 1.6 millimeters, or one sixteenth inch, in diameter.) Conversely, particulate can be reduced significantly when overfire air pressures are increased.[5]

The primary kinds of particulate control devices used for coal combustion include multiple cyclones, electrostatic precipitators, fabric filters (baghouses) and scrubbers. Some measure of control will even result from ash settling in boiler/air heater/economizer dust hoppers, large breeches and chimney bases. To the extent possible from the existing data base, the effects of such settling are reflected in the emission factors in Table 1.1-1.

Electrostatic precipitators (ESP) are the most common high efficiency control device used on pulverized coal and cyclone units, and they are being used increasingly on stokers. Generally, ESP collection efficiencies are a function of collection plate area per volumetric flow rate of flue gas through the device. Particulate control efficiencies of 99.9 weight percent are obtainable with ESPs. Fabric filters have recently seen increased use in both utility and industrial applications, generally effecting about 99.8 percent efficiency. An advantage of fabric filters is that they are unaffected by high flyash resistivities associated with low sulfur coals. ESPs located after air preheaters (i. e., cold side precipitators) may operate at significantly reduced efficiencies when low sulfur coal is fired. Scrubbers are also used to control particulate, although their primary use is to control sulfur oxides. One drawback of scrubbers is the high energy requirement to achieve control efficiencies comparable to those of ESPs and baghouses.[2]

Mechanical collectors, generally multiple cyclones, are the primary means of control on many stokers and are sometimes installed upsteam of high efficiency control devices in order to reduce the ash collection burden. Depending on application and design, multiple cyclone efficiencies can vary tremendously. Where cyclone design flow rates are not attained (which is common with underfeed and overfeed stokers), these devices may be only marginally effective and may prove little better in reducing particulate than large breeching. Conversely, well designed multiple cyclones, operating at the required flow rates, can achieve collection efficiencies on spreader stokers and overfeed stokers of 90 to 95 percent. Even higher collection efficiencies are obtainable on spreader stokers with reinjected flyash, because of the larger particle sizes and increased particulate loading reaching the controls.[5-6]

Sulfur Oxides[7-9] - Gaseous sulfur oxides from external coal combustion are largely sulfur dioxide (SO_2) and much less quantity of sulfur trioxide (SO_3) and gaseous sulfates. These compounds form as the organic and pyritic sulfur in the coal is oxidized during the combustion process. On average, 98 percent of the sulfur present in bituminous coal will be emitted as gaseous sulfur oxides, whereas somewhat less will be emitted when subbituminous coal is fired. The more alkaline nature of the ash in some subbituminous coal causes some of the sulfur to react to form various sulfate salts that are retained in the boiler or in the flyash. Generally, boiler size, firing configuration and boiler operations have little effect on the percent conversion of fuel sulfur to sulfur oxides.

Several techniques are used to reduce sulfur oxides from coal combustion. One way is to switch to lower sulfur coals, since sulfur oxide emissions are proportional to the sulfur content of the coal. This alternative may not be possible where lower sulfur coal is not readily available or where a different grade of coal can not be satisfactorily fired. In some cases, various cleaning processes may be employed to reduce the fuel sulfur content. Physical coal cleaning removes mineral sulfur such as pyrite but is not effective in removing organic sulfur. Chemical cleaning and solvent refining processes are being developed to remove organic sulfur.

Many flue gas desulfurization techniques can remove sulfur oxides formed during combustion. Flue gases can be treated through wet, semidry or dry desulfurization processes of either the throwaway type, in which all waste streams are discarded, or the recovery (regenerable) type, in which the SO_x absorbent is regenerated and reused. To date, wet systems are the most commonly applied. Wet systems generally use alkali slurries as the SO_x absorbent medium and can be designed to remove well in excess of 90 percent of the incoming SO_x. Particulate reduction of up to 99 percent is also possible with wet scrubbers, but flyash is often collected by upsteam ESPs or baghouses, to avoid erosion of the desulfurization equipment and possible interference with the process reactions.[7] Also, the volume of scrubber sludge is reduced with separate flyash removal, and contamination of the reagents and byproducts is prevented. References 7 and 8 give more details on scrubbing and other SO_x removal techniques.

Nitrogen Oxides [10-11] - Nitrogen oxides (NO_x) emissions from coal combustion are primarily nitrogen oxide (NO). Only a few volume percent are nitrogen dioxide (NO_2). NO results from thermal fixation of atmospheric nitrogen in the combustion flame and from oxidation of nitrogen bound in the coal. Typically, only 20 to 60 percent of the fuel nitrogen is converted to nitrogen oxides. Bituminous and subbituminous coals usually contain from 0.5 to 2 weight percent nitrogen, present mainly in aromatic ring structures. Fuel nitrogen can account for up to 80 percent of total NO_x from coal combustion.

A number of combustion modifications can be made to reduce NO_x emissions from boilers. Low excess air (LEA) firing is the most widespread control modification, because it can be practiced in both old and new units and in all sizes of boilers. LEA firing is easy to implement and has the added advantage of increasing fuel use efficiency. LEA firing is generally effective only above 20 percent excess air for pulverized coal units and above 30 percent excess air for stokers. Below these levels, the NO_x reduction from decreased O_2 availability is offset by increased NO_x because of increased flame temperature. Another NO_x reduction technique is simply to switch to a coal having a lower nitrogen content, although many boilers may not properly fire coals of different properties.

Off-stoichiometric (staged) combustion is also an effective means of controlling NO_x from coal fired equipment. This can be achieved by using overfire air or low NO_x burners designed to stage combustion in the flame zone. Other NO_x reduction techniques include flue gas recirculation, load reduction, and steam or water injection. However, these techniques are not very effective for use on coal fired equipment because of the fuel nitrogen effect. Ammonia injection is another technique which can be used, but it is costly. The net reduction of NO_x from any of these techniques or combinations thereof varies considerably with boiler type, coal properties and existing operating practices. Typical reductions will range from 10 to 60 percent. References 10 and 60 should be consulted for a detailed discussion of each of these NO_x reduction techniques. To date, flue gas treatment is not used to reduce nitrogen oxide emissions because of its higher cost.

Volatile Organic Compounds And Carbon Monoxide - Volatile organic compounds (VOC) and carbon monoxide (CO) are unburnt gaseous combustibles which generally are emitted in quite small amounts. However, during startups, temporary upsets or other conditions preventing complete combustion, unburnt combustible emissions may increase dramatically. VOC and CO emissions per unit of fuel fired are normally lower from pulverized coal or cyclone furnaces than from smaller stokers and handfired units where operating conditions are not so well controlled. Measures used for NO_x control can increase CO emissions, so to reduce the risk of explosion, such measures are applied only to the point at which CO in the flue gas reaches a maximum of about 200 parts per million. Other than maintaining proper combustion conditions, control measures are not applied to control VOC and CO.

Emission Factors And References - Emission factors for several pollutants are presented in Table 1.1-1, and factor ratings and references are presented in Table 1.1-2. The factors for uncontrolled underfeed stokers and hand fired units also may be applied to hot air furnaces. Tables 1.1-3 through 1.1-8 present cumulative size distribution data and size specific emission factors for particulate emissions from the combustion sources discussed above. Uncontrolled and controlled size specific emission factors are presented in Figures 1.1-1 through 1.1-6.

TABLE 1.1-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR DRY BOTTOM BOILERS BURNING PULVERIZED BITUMINOUS COAL[a]

EMISSION FACTOR RATING: C (uncontrolled)
D (scrubber and ESP controlled
E (multiple cyclone and baghouse)

Particle size[b] (µm)	Cumulative mass % ≤ stated size					Cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]				
	Uncontrolled	Controlled				Uncontrolled	Controlled[d]			
		Multiple cyclone	Scrubber	ESP	Baghouse		Multiple cyclone	Scrubber	ESP	Baghouse
15	32	54	81	79	97	1.6A (3.2A)	0.54A (1.08A)	0.24A (0.48A)	0.032A (0.06A)	0.010A (0.02A)
10	23	29	71	67	92	1.15A (2.3A)	0.29A (0.58A)	0.21A (0.42A)	0.027A (0.05A)	0.009A (0.02A)
6	17	14	62	50	77	0.85A (1.7A)	0.14A (0.28A)	0.19A (0.38A)	0.020A (0.04A)	0.008A (0.02A)
2.5	6	3	51	29	53	0.30A (0.6A)	0.03A (0.06A)	0.15A (0.3A)	0.012A (0.02A)	0.005A (0.01A)
1.25	2	1	35	17	31	0.10A (0.2A)	0.01A (0.02A)	0.11A (0.22A)	0.007A (0.01A)	0.003A (0.006A)
1.00	2	1	31	14	25	0.10A (0.2A)	0.01A (0.02A)	0.09A (0.18A)	0.006A (0.01A)	0.003A (0.006A)
0.625	1	1	20	12	14	0.05A (0.10)	0.01A (0.02A)	0.06A (0.12A)	0.005A (0.01A)	0.001A (0.002A)
TOTAL	100	100	100	100	100	5A (10A)	1A (2A)	0.3A (0.6A)	0.04A (0.08A)	0.01A (0.02A)

[a] Reference 61. ESP = electrostatic precipitator.

[b] Expressed as aerodynamic equivalent diameter.

[c] A = coal ash weight %, as fired.

[d] Estimated control efficiency for multiple cyclone, 80%; scrubber, 94%; ESP, 99.2%; baghouse, 99.8%.

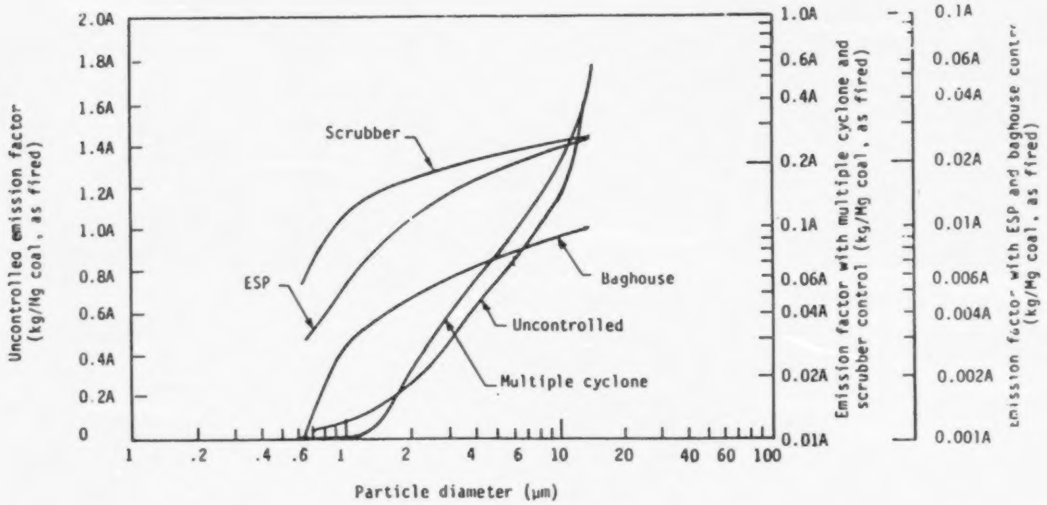

Figure 1.1-1. Cumulative size specific emission factors for dry bottom boilers burning pulverized bituminous coal.

TABLE 1.1-4. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR WET BOTTOM BOILERS BURNING PULVERIZED BITUMINOUS COAL[a]

EMISSION FACTOR RATING: E

Particle size[b] (μm)	Cumulative mass % ≤ stated size			Cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]		
	Uncontrolled	Controlled		Uncontrolled	Controlled[d]	
		Multiple cyclone	ESP		Multiple cyclone	ESP
15	40	99	83	1.4A (2.8A)	0.69A (1.38A)	0.023A (0.046A)
10	37	93	75	1.30A (2.6A)	0.65A (1.3A)	0.021A (0.042A)
6	33	84	63	1.16A (2.32A)	0.59A (1.18A)	0.018A (0.036A)
2.5	21	61	40	0.74A (1.48A)	0.43A (0.86A)	0.011A (0.022A)
1.25	6	31	17	0.21A (0.42A)	0.22A (0.44A)	0.005A (0.01A)
1.00	4	19	8	0.14A (0.28A)	0.13A (0.26A)	0.002A (0.004A)
0.625	2	e	e	0.07A (0.14A)	e	e
TOTAL	100	100	100	3.5A (7.0A)	0.7A (1.4A)	0.028A (0.056A)

[a] Reference 61. ESP = electrostatic precipitator.
[b] Expressed as aerodynamic equivalent diameter.
[c] A = coal ash weight %, as fired.
[d] Estimated control efficiency for multiple cyclone, 80%; ESP, 99.2%.
[e] Insufficient data.

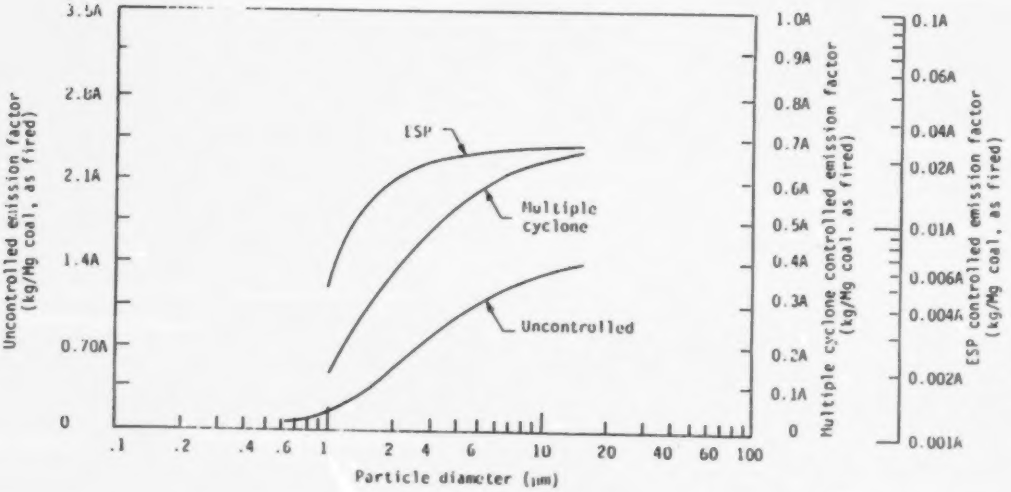

Figure 1.1-2. Cumulative size specific emission factors for wet bottom boilers burning pulverized bituminous coal

TABLE 1.1-5. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR CYCLONE FURNACES BURNING BITUMINOUS COAL[a]

EMISSION FACTOR RATING: E

Particle size[b] (μm)	Cumulative mass % ≤ stated size			Cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]		
	Uncontrolled	Controlled		Uncontrolled	Controlled[e]	
		Scrubber	ESP		Scrubber	ESP
15	33	95	90	0.33A (0.66A)	0.057A (0.114A)	0.0064A (0.013A)
10	13	94	68	0.13A (0.26A)	0.056A (0.112A)	0.0054A (0.011A)
6	8	93	56	0.08A (0.16A)	0.056A (0.112A)	0.0045A (0.009A)
2.5	0	92	36	0 (0)	0.055A (0.11A)	0.0029A (0.006A)
1.25	0	85	22	0 (0)	0.051A (0.10A)	0.0018A (0.004A)
1.00	0	82	17	0 (0)	0.049A (0.10A)	0.0014A (0.003A)
0.625	0	d	d	0 (0)	d	d
TOTAL	100	100	100	1A (2A)	0.06A (0.12A)	0.008A (0.016A)

[a] Reference 61. ESP = electrostatic precipitator.
[b] Expressed as aerodynamic equivalent diameter.
[c] A = coal ash weight %, as fired.
[d] Insufficient data.
[e] Estimated control efficiency for scrubber, 94%; ESP, 99.2%.

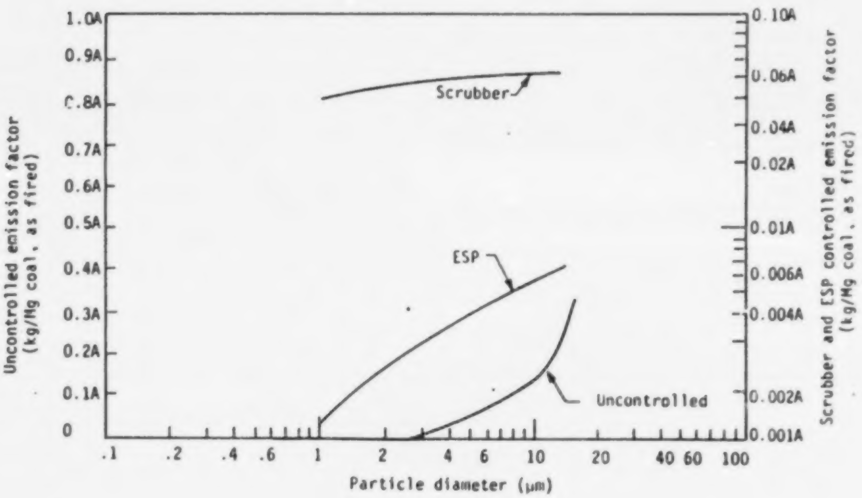

Figure 1.1-3. Cumulative size specific emission factors for cyclone furnaces burning bituminous coal

TABLE 1.1-6. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR SPREADER STOKERS BURNING BITUMINOUS COAL[a]

EMISSION FACTOR RATING: C (uncontrolled and controlled for multiple cyclone without flyash reinjection, and with baghouse)
E (multiple cyclone controlled with flyash reinjection, and ESP controlled)

Particle size[b] (µm)	Cumulative mass % ≤ stated size					Cumulative emission factor [kg/Mg (lb/ton) coal, as fired]				
	Uncontrolled	Controlled				Uncontrolled	Controlled			
		Multiple cyclone[c]	Multiple cyclone[d]	ESP	Baghouse		Multiple cyclone[c]	Multiple cyclone[d]	ESP	Baghouse
15	28	86	74	97	72	8.4 (16.8)	7.3 (14.6)	4.4 (8.8)	0.23 (0.46)	0.043 (0.086)
10	20	73	65	90	60	6.0 (12.0)	6.2 (12.4)	3.9 (7.8)	0.22 (0.44)	0.036 (0.072)
6	14	51	52	82	46	4.2 (8.4)	4.3 (8.6)	3.1 (6.2)	0.20 (0.40)	0.028 (0.056)
2.5	7	8	27	61	26	2.1 (4.2)	0.7 (1.4)	1.6 (3.2)	0.15 (0.30)	0.016 (0.032)
1.25	5	2	16	46	18	1.5 (3.0)	0.2 (0.4)	1.0 (2.0)	0.11 (0.22)	0.011 (0.022)
1.00	5	2	14	41	15	1.5 (3.0)	0.2 (0.4)	0.8 (1.6)	0.10 (0.20)	0.009 (0.018)
0.625	4	1	9	e	7	1.2 (2.4)	0.1 (0.2)	0.5 (1.0)	e	0.004 (0.008)
TOTAL	100	100	100	100	100	30.0 (60.0)	8.5 (17.0)	6.0 (12.0)	0.24[f] (0.48)	0.06[f] (0.12)

[a] Reference 61. ESP = electrostatic precipitator.
[b] Expressed as aerodynamic equivalent diameter.
[c] With flyash reinjection.
[d] Without flyash reinjection.
[e] Insufficient data.
[f] Estimated control efficiency for ESP, 99.2%; baghouse, 99.8%.

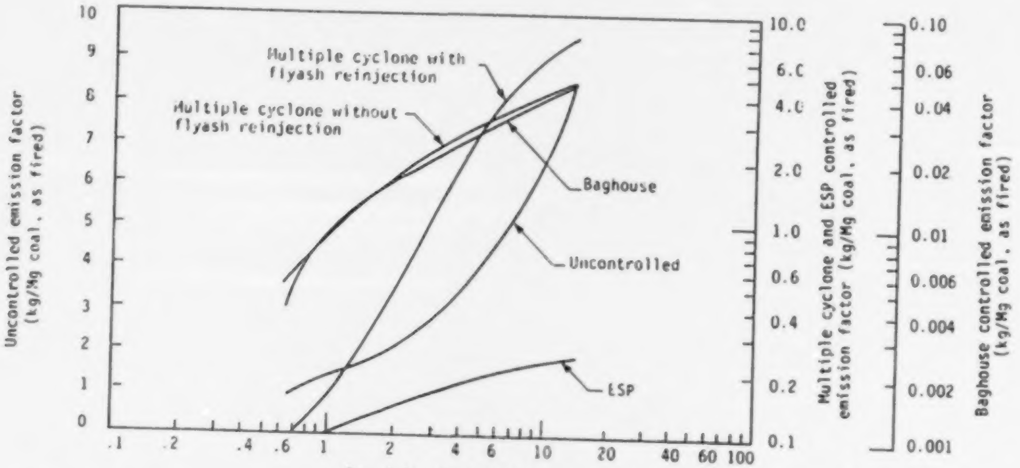

Figure 1.1-4. Cumulative size specific emission factors for spreader stokers burning bituminous coal

TABLE 1.1-7. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR OVERFEED STOKERS BURNING BITUMINOUS COAL[a]

EMISSION FACTOR RATING: C (uncontrolled)
E (multiple cyclone controlled)

Particle size[b] (μm)	Cumulative mass % ≤ stated size		Cumulative emission factor [kg/Mg (lb/ton) coal, as fired]	
	Uncontrolled	Multiple cyclone controlled	Uncontrolled	Multiple cyclone controlled[d]
15	49	60	3.9 (7.8)	2.7 (5.4)
10	37	55	3.0 (6.0)	2.5 (5.0)
6	24	49	1.9 (3.8)	2.2 (4.4)
2.5	14	43	1.1 (2.2)	1.9 (3.8)
1.25	13	39	1.0 (2.0)	1.8 (3.6)
1.00	12	39	1.0 (2.0)	1.8 (3.6)
0.625	c	16	c	0.7 (1.4)
TOTAL	100	100	8.0 (16.0)	4.5 (9.0)

[a] Reference 61.
[b] Expressed as aerodynamic equivalent diameter.
[c] Insufficient data.
[d] Estimated control efficiency for multiple cyclone, 80%.

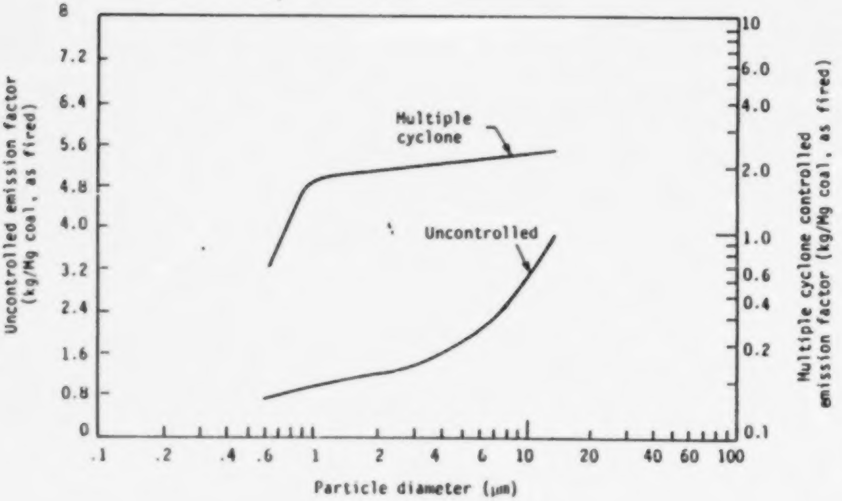

Figure 1.1-5. Cumulative size specific emission factors for overfeed stokers burning bituminous coal

TABLE 1.1-8. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR UNDERFEED STOKERS BURNING BITUMINOUS COAL[a]

EMISSION FACTOR RATING: C

Particle size[b] (µm)	Cumulative mass % ≤ stated size	Uncontrolled cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]
15	50	3.8 (7.6)
10	41	3.1 (6.2)
6	32	2.4 (4.8)
2.5	25	1.9 (3.8)
1.25	22	1.7 (3.4)
1.00	21	1.6 (3.2)
0.625	18	1.4 (2.7)
TOTAL	100	7.5 (15.0)

[a] Reference 61.

[b] Expressed as aerodynamic equivalent diameter.

[c] May also be used for uncontrolled hand fired units.

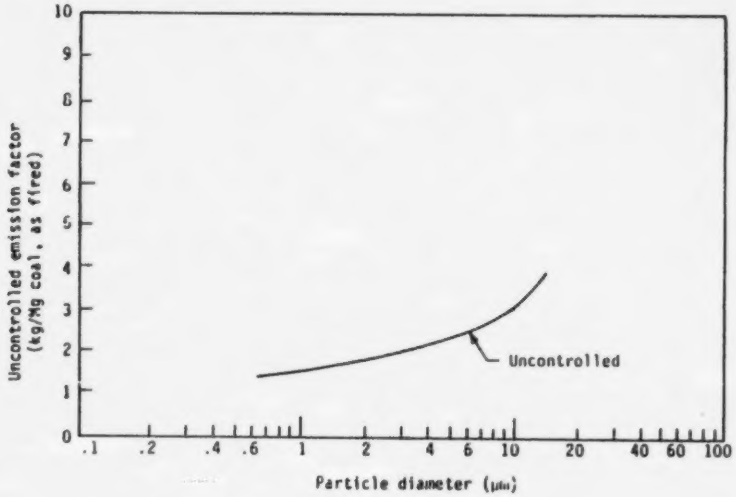

Figure 1.1-6. Cumulative size specific emission factors for underfeed stokers burning bituminous coal.

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1.2 ANTHRACITE COAL COMBUSTION

1.2.1 General[1-2]

Anthracite coal is a high rank coal with more fixed carbon and less volatile matter than either bituminous coal or lignite, and it has higher ignition and ash fusion temperatures. Because of its low volatile matter content and slight clinkering, anthracite is most commonly fired in medium sized traveling grate stokers and small hand fired units. Some anthracite (occasionally with petroleum coke) is used in pulverized coal fired boilers. It is also blended with bituminous coal. None is fired in spreader stokers. For its low sulfur content (typically less than 0.8 weight percent) and minimal smoking tendencies, anthracite is considered a desirable fuel where readily available.

In the United States, all anthracite is mined in northeastern Pennsylvania and is consumed mostly in Pennsylvania and several surrounding states. The largest use of anthracite is for space heating. Lesser amounts are employed for steam/electric production; coke manufacturing, sintering and pelletizing; and other industrial uses. Anthracite currently is only a small fraction of the total quantity of coal combusted in the United States.

1.2.2 Emissions And Controls[2-14]

Particulate emissions from anthracite combustion are a function of furnace firing configuration, firing practices (boiler load, quantity and location of underfire air, sootblowing, flyash reinjection, etc.), and the ash content of the coal. Pulverized coal fired boilers emit the highest quantity of particulate per unit of fuel because they fire the anthracite in suspension, which results in a high percentage of ash carryover into exhaust gases. Pulverized anthracite fired boilers operate in the dry tap or dry bottom mode, because of anthracite's characteristically high ash fusion temperature. Traveling grate stokers and hand fired units produce much less particulate per unit of fuel fired, because combustion takes place in a quiescent fuel bed without significant ash carryover into the exhaust gases. In general, particulate emissions from traveling grate stokers will increase during sootblowing and flyash reinjection and with higher fuel bed underfeed air from forced draft fans. Smoking is rarely a problem, because of anthracite's low volatile matter content.

Limited data are available on the emission of gaseous pollutants from anthracite combustion. It is assumed from bituminous coal combustion data that a large fraction of the fuel sulfur is emitted as sulfur oxides. Also, because combustion equipment, excess air rates, combustion temperatures, etc., are similar between anthracite and bituminous coal combustion, nitrogen oxide and carbon monoxide emissions are assumed to be similar, too. Volatile organic compound (VOC) emissions, however, are expected to be considerably lower, since the volatile matter content of anthracite is significantly less than that of bituminous coal.

TABLE 1.2-1. UNCONTROLLED EMISSION FACTORS FOR ANTHRACITE COMBUSTION[a]

Boiler type	Particulate[b]		Sulfur oxides[c]		Nitrogen oxides[d]		Carbon monoxide[e]		Volatile organics	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	Nonmethane	Methane
Pulverized coal fired	f	f	19.5S	39S	9	18	f	f	f	f
Traveling grate stoker	4.6[g]	9.1[g]	19.5S	39S	5	10	0.3	0.6	f	f
Hand fed units	5[h]	10[h]	19.5S	39S	1.5	3	f	f	f	f

[a] Factors are for uncontrolled emissions and should be applied to coal consumption as fired.

[b] Based on EPA Method 5 (front half catch).

[c] Assumes, as with bituminous coal combustion, most fuel sulfur is emitted as SO_x. Limited data in Reference 5 verify this for pulverized anthracite fired boilers. Emissions are mostly SO_2, with 1 - 3% SO_3. S indicates that weight % sulfur should be multiplied by the value given.

[d] For pulverized anthracite fired boilers and hand fed units, assumed to be similar to bituminous coal combustion. For traveling grate stokers, see References 8, 11.

[e] May increase by several orders of magnitude with boilers not properly operated or maintained. For traveling grate stokers, based on limited information in Reference 8. For pulverized coal fired boilers, substantiated by additional data in Reference 14.

[f] Factors in Table 1.1-1 may be used, based on similarity of anthracite and bituminous coal.

[g] References 12-13, 15-18. Accounts for limited fallout that may occur in fallout chambers and stack breeching. Factors for individual boilers may be 2.5 - 25 kg/Mg (5 - 50 lb/ton), highest during soot blowing.

[h] Reference 2.

Controls on anthracite emissions mainly have been applied to particulate matter. The most efficient particulate controls, fabric filters, scrubbers and electrostatic precipitators, have been installed on large pulverized anthracite fired boilers. Fabric filters and venturi scrubbers can effect collection efficiencies exceeding 99 percent. Electrostatic precipitators typically are only 90 to 97 percent efficient, because of the characteristic high resistivity of low sulfur anthracite fly ash. It is reported that higher efficiencies can be achieved using larger precipitators and flue gas conditioning. Mechanical collectors are frequently employed upstream from these devices for large particle removal.

Traveling grate stokers are often uncontrolled. Indeed, particulate control has often been considered unnecessary, because of anthracite's low smoking tendencies and of the fact that a significant fraction of large size flyash from stokers is readily collected in flyash hoppers as well as in the breeching and base of the stack. Cyclone collectors have been employed on traveling grate stokers, and limited information suggests these devices may be up to 75 percent efficient on particulate. Flyash reinjection, frequently used in traveling grate stokers to enhance fuel use efficiency, tends to increase particulate emissions per unit of fuel combusted.

Emission factors for pollutants from anthracite coal combustion are given in Table 1.2-1, and factor ratings in Table 1.2-2. Cumulative size distribution data and size specific emission factors and ratings for particulate emissions are in Tables 1.2-3 and 1.2-4. Uncontrolled and controlled size specific emission factors are presented in Figures 1.2-1 and 1.2-2. Size distribution data for bituminous coal combustion may be used for uncontrolled emissions from pulverized anthracite fired furnaces, and data for anthracite fired traveling grate stokers may be used for hand fired units.

TABLE 1.2-2. ANTHRACITE COAL EMISSION FACTOR RATINGS

Furnace type	Particulate	Sulfur oxides	Nitrogen oxides	Carbon monoxide	Volatile organics	
					Nonmethane	Methane
Pulverized coal	B	B	B	B	C	C
Traveling grate stoker	B	B	B	B	C	C
Hand fired units	B	B	B	B	D	D

TABLE 1.2-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR DRY BOTTOM BOILERS BURNING PULVERIZED ANTHRACITE COAL[a]

EMISSION FACTOR RATING: D

Particle size[b] (um)	Cumulative mass % ≤ stated size			Cumulative emission factor[c] [kg/Mg (lb/ton) bark, as fired]		
	Uncontrolled	Controlled		Uncontrolled	Controlled[d]	
		Multiple cyclone	Baghouse		Multiple cyclone	Baghouse
15	32	63	79	1.6A (3.2A)	0.63A (1.26A)	0.0079A (0.016A)
10	23	55	67	1.2A (2.3A)	0.55A (1.10A)	0.0067A (0.013A)
6	17	46	51	0.9A (1.7A)	0.46A (0.92A)	0.0051A (0.010A)
2.5	6	24	32	0.3A (0.6A)	0.24A (0.48A)	0.0032A (0.006A)
1.25	2	13	21	0.1A (0.2A)	0.13A (0.26A)	0.0021A (0.004A)
1.00	2	10	18	0.1A (0.2A)	0.10A (0.20A)	0.0018A (0.004A)
0.625	1	7		0.05A (0.1A)	0.07A (0.14A)	e
TOTAL	100	100	100	5A (10A)	1A (2A)	0.01A (0.02A)

[a] Reference 19.

[b] Expressed as aerodynamic equivalent diameter.

[c] A = coal ash weight, as fired.

[d] Estimated control efficiency for multiple cyclone, 80%; baghouse, 99.8%.

[e] Insufficient data.

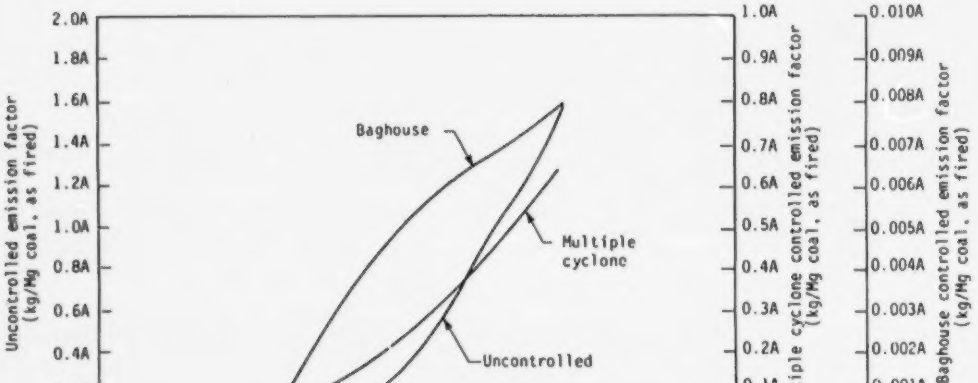

Figure 1.2-1. Cumulative size specific emission factors for dry bottom boilers burning pulverized anthracite coal.

TABLE 1.2-4. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR TRAVELING GRATE STOKERS BURNING ANTHRACITE COAL[a]

EMISSION FACTOR RATING: E

Particle size[b] (um)	Cumulative mass % ≤ stated size	Cumulative emission factor [kg/Mg (lb/ton) coal, as fired]
	Uncontrolled[c]	Uncontrolled
15	64	2.9 (5.8)
10	52	2.4 (4.8)
6	42	1.9 (3.8)
2.5	27	1.2 (2.4)
1.25	24	1.1 (2.2)
1.00	23	1.1 (2.2)
0.625	d	d
TOTAL	100	4.6 (9.2)

[a] Reference 19.
[b] Expressed as aerodynamic equivalent diameter.
[c] May also be used for uncontrolled hand fired units.
[d] Insufficient data.

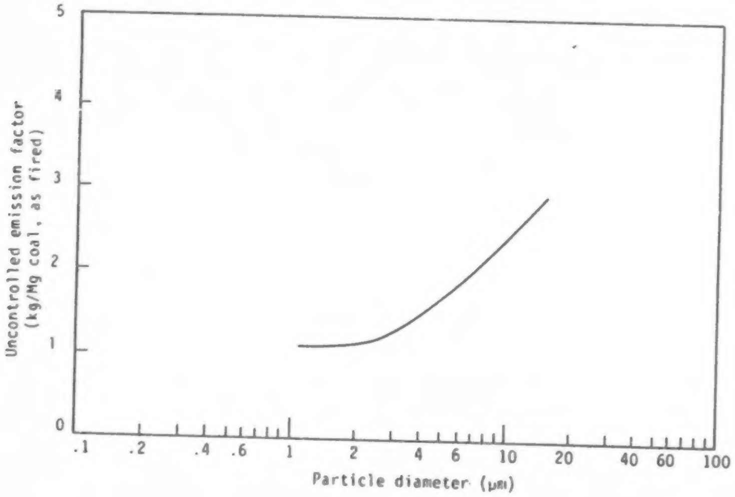

Figure 1.2-2. Cumulative size specific emission factors for traveling grate stokers burning anthracite coal.

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1.3 FUEL OIL COMBUSTION

1.3.1 General[1-2,22]

Fuel oils are broadly classified into two major types, distillate and residual. Distillate oils (fuel oil grade Nos. 1 and 2) are used mainly in domestic and small commercial applications in which easy fuel burning is required. Distillates are more volatile and less viscous that residual oils, having negligible ash and nitrogen contents and usually containing less than 0.3 weight percent sulfur. Residual oils (grade Nos. 4, 5 and 6), on the other hand, are used mainly in utility, industrial and large commercial applications with sophisticated combustion equipment. No. 4 oil is sometimes classified as a distillate, and No. 6 is sometimes referred to as Bunker C. Being more viscous and less volatile than distillate oils, the heavier residual oils (Nos. 5 and 6) must be heated to facilitate handling and proper atomization. Because residual oils are produced from the residue after lighter fractions (gasoline, kerosene and distillate oils) have been removed from the crude oil, they contain significant quantities of ash, nitrogen and sulfur. Properties of typical fuel oils can be found in Appendix A.

1.3.2 Emissions

Emissions from fuel oil combustion depend on the grade and composition of the fuel, the type and size of the boiler, the firing and loading practices used, and the level of equipment maintenance. Table 1.3-1 presents emission factors for fuel oil combustion pollutants, and Tables 1.3-2 through 1.3-5 present cumulative size distribution data and size specific emission factors for particulate emissions from fuel oil combustion. Uncontrolled and controlled size specific emission factors are presented in Figures 1.3-1 through 1.3-4. Distillate and residual oil categories are given separately, because their combustion produces significantly different particulate, SO_2 and NO_x emissions.

Particulate Matter[3-7,12-13,24,26-27] - Particulate emissions depend most on the grade of fuel fired. The lighter distillate oils result in particulate formation significantly lower than with heavier residual oils. Among residual oils, Nos. 4 and 5 usually produce less particulate than does the heavier No. 6.

In boilers firing No. 6, particulate emissions can be described, on the average, as a function of the sulfur content of the oil. As shown in Table 1.3-1), particulate emissions can be reduced considerably when low sulfur No. 6 oil is fired. This is because low sulfur No. 6, either refined from naturally low sulfur crude oil or desulfurized by one of several current processes, exhibits substantially lower viscosity and reduced asphaltene, ash and sulfur, which results in better atomization and cleaner combustion.

Boiler load can also affect particulate emissions in units firing No. 6 oil. At low load conditions, particulate emissions may be lowered 30 to 40 percent from utility boilers and by as much as 60 percent from small industrial and commercial units. No significant particulate reductions have been noted at

TABLE 1.3-1. UNCONTROLLED EMISSION FACTORS FOR FUEL OIL COMBUSTION

EMISSION FACTOR RATING: A

Boiler Type[a]	Particulate Matter[b]		Sulfur Dioxide[c]		Sulfur Trioxide		Carbon Monoxide[d]		Nitrogen Oxide[e]		Volatile Organics[f] Nonmethane		Volatile Organics[f] Methane	
	kg/10³l	lb/10³gal	kg/10³l	lb/10³gal	kg/10³l	lb/10³gal	kg/10³l	lb/10³gal	kg/10³l	lb/10³gal	kg/10³l	lb/10³gal	kg/10³l	lb/10³gal
Utility Boilers														
Residual Oil	[g]	[g]	19S	157S	0.34S[h]	2.9S[h]	0.6	5	8.0 (12.6)(5)[i]	67 (105)(42)[i]	0.09	0.76	0.03	0.28
Industrial Boilers														
Residual Oil	[g]	[g]	19S	157S	0.24S	2S	0.6	5	6.6[j]	55[j]	0.034	0.28	0.12	1.0
Distillate Oil	0.24	2	17S	142S	0.24S	2S	0.6	5	2.4	20	0.024	0.2	0.006	0.052
Commercial Boilers														
Residual Oil	[g]	[g]	19S	157S	0.24S	2S	0.6	5	6.6	55	0.14	1.13	0.057	0.475
Distillate Oil	0.24	2	17S	142S	0.24S	2S	0.6	5	2.4	20	0.04	0.34	0.026	0.216
Residential Furnaces														
Distillate Oil	0.3	2.5	17S	142S	0.24S	2S	0.6	5	2.2	18	0.085	0.713	0.214	1.78

[a] Boilers can be approximately classified according to their gross (higher) heat rate as shown below:
Utility (power plant) boilers: $>106 \times 10^9$ J/hr ($>100 \times 10^6$ Btu/hr)
Industrial boilers: 10.6×10^9 to 106×10^9 J/hr (10×10^6 to 100×10^6 Btu/hr)
Commercial boilers: 0.5×10^9 to 10.6×10^9 J/hr (0.5×10^6 to 10×10^6 Btu/hr)
Residential furnaces: $<0.5 \times 10^9$ J/hr ($<0.5 \times 10^6$ Btu/hr)

[b] References 3-7 and 24-25. Particulate matter is defined in this section as that material collected by EPA Method 5 (front half catch).

[c] References 1-5. S indicates that the weight % of sulfur in the oil should be multiplied by the value given.

[d] References 3-5 and 8-10. Carbon monoxide emissions may increase by factors of 10 to 100 if the unit is improperly operated or not well maintained.

[e] Expressed as NO_2. References 1-5, 8-11, 17 and 26. Test results indicate that at least 95% by weight of NO_x is NO for all boiler types except residential furnaces, where about 75% is NO.

[f] References 18-21. Volatile organic compound emissions are generally negligible unless boiler is improperly operated or not well maintained, in which case emissions may increase by several orders of magnitude.

[g] Particulate emission factors for residual oil combustion are, on average, a function of fuel oil grade and sulfur content:
Grade 6 oil: $1.25(S) + 0.38$ kg/10³ liter [$10(S) + 3$ lb/10³ gal] where S is the weight % of sulfur in the oil. This relationship is based on 81 individual tests and has a correlation coefficient of 0.65.
Grade 5 oil: 1.25 kg/10³ liter (10 lb/10³ gal)
Grade 4 oil: 0.88 kg/10³ liter (7 lb/10³ gal)

[h] Reference 25.

[i] Use 5 kg/10³ liters (42 lb/10³ gal) for tangentially fired boilers, 12.6 kg/10³ liters (105 lb/10³gal) for vertical fired boilers, and 8.0 kg/10³ liters (67 lb/10³ gal) for all others, at full load and normal (>15%) excess air. Several combustion modifications can be employed for NO_x reduction: (1) limited excess air can reduce NO_x emissions 5-20%, (2) staged combustion 20-40%, (3) using low NO_x burners 20-50%, and (4) ammonia injection can reduce NO_x emissions 40-70% but may increase emissions of ammonia. Combinations of these modifications have been employed for further reductions in certain boilers. See Reference 23 for a discussion of these and other NO_x reducing techniques and their operational and environmental impacts.

[j] Nitrogen oxides emissions from residual oil combustion in industrial and commercial boilers are strongly related to fuel nitrogen content, estimated more accurately by the empirical relationship:
kg NO_2/10³ liters = $2.75 + 50(N)^2$ [lb NO_2/10³gal = $22 + 400(N)^2$] where N is the weight % of nitrogen in the oil. For residual oils having high (>0.5 weight %) nitrogen content, use 15 kg NO_2/10³ liter (120 lb NO_2/10³gal) as an emission factor.

low loads from boilers firing any of the lighter grades, however. At too low a load condition, proper combustion conditions cannot be maintained, and particulate emissions may increase drastically. It should be noted, in this regard, that any condition that prevents proper boiler operation can result in excessive particulate formation.

Sulfur Oxides [1-5,25,27] - Total SO_x emissions are almost entirely dependent on the sulfur content of the fuel and are not affected by boiler size, burner design, or grade of fuel being fired. On the average, more than 95 percent of the fuel sulfur is emitted as SO_2, about 1 to 5 percent as SO_3 and about 1 to 3 percent as sulfate particulate. SO_3 readily reacts with water vapor (in both air and flue gases) to form a sulfuric acid mist.

Nitrogen Oxides [1-11,4,17,23,27] - Two mechanisms form NO_x, oxidation of fuelbound nitrogen and thermal fixation of the nitrogen in combustion air. Fuel NO_x is primarily a function of the nitrogen content of the fuel and the available oxygen. On average, about 45 percent of the fuel nitrogen is converted to NO_x, but this may vary from 20 to 70 percent. Thermal NO_x, rather, is largely a function of peak flame temperature and available oxygen, factors which depend on boiler size, firing configuration and operating practices.

Fuel nitrogen conversion is the more important NO_x forming mechanism in residual oil boilers. Except in certain large units having unusually high peak flame temperatures, or in units firing a low nitrogen residual oil, fuel NO_x will generally account for over 50 percent of the total NO_x generated. Thermal fixation, on the other hand, is the dominant NO_x forming mechanism in units firing distillate oils, primarily because of the negligible nitrogen content in these lighter oils. Because distillate oil fired boilers usually have low heat release rates, however, the quantity of thermal NO_x formed in them is less than that of larger units.

A number of variables influence how much NO_x is formed by these two mechanisms. One important variable is firing configuration. Nitrogen oxide emissions from tangentially (corner) fired boilers are, on the average, less than those of horizontally opposed units. Also important are the firing practices employed during boiler operation. Limited excess air firing, flue gas recirculation, staged combustion, or some combination thereof may result in NO_x reductions of 5 to 60 percent. See Section 1.4 for a discussion of these techniques. Load reduction can likewise decrease NO_x production. Nitrogen oxide emissions may be reduced from 0.5 to 1 percent for each percentage reduction in load from full load operation. It should be noted that most of these variables, with the exception of excess air, infuence the NO_x emissions only of large oil fired boilers. Limited excess air firing is possible in many small boilers, but the resulting NO_x reductions are not nearly so significant.

Other Pollutants[18-21] - As a rule, only minor amounts of volatile organic compounds (VOC) and carbon monoxide will be emitted from the combustion of fuel oil. The rate at which VOCs are emitted depends on combustion efficiency. Emissions of trace elements from oil fired boilers are relative to the trace element concentrations of the oil.

TABLE 1.3-2. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR UTILITY BOILERS FIRING RESIDUAL OIL[a]

EMISSION FACTOR RATING: C (uncontrolled)
E (ESP controlled)
D (scrubber controlled)

Particle size[b] (um)	Cumulative mass % ≤ stated size			Cumulative emission factor[c] [kg/10^3 l (lb/10^3 gal)]		
	Uncontrolled	Controlled		Uncontrolled	Controlled[d]	
		ESP	Scrubber		ESP	Scrubber
15	80	75	100	0.80A (6.7A)	0.0060A (0.05A)	0.06A (0.50A)
10	71	63	100	0.71A (5.9A)	0.0050A (0.042A)	0.06A (0.50A)
6	58	52	100	0.58A (4.8A)	0.0042A (0.035A)	0.06A (0.50A)
2.5	52	41	97	0.52A (4.3A)	0.0033A (0.028A)	0.058A (0.48A)
1.25	43	31	91	0.43A (3.6A)	0.0025A (0.021A)	0.055A (0.46A)
1.00	39	28	84	0.39A (3.3A)	0.0022A (0.018A)	0.050A (0.42A)
0.625	20	10	64	0.20A (1.7A)	0.0008A (0.007A)	0.038A (0.32A)
TOTAL	100	100	100	1A (8.3A)	0.008A (0.067A)	0.06A (0.50A)

[a] Reference 29. ESP = electrostatic precipitator.

[b] Expressed as aerodynamic equivalent diameter.

[c] Particulate emission factors for residual oil combustion without emission controls are, on average, a function of fuel oil grade and sulfur content:
Grade 6 Oil: $A = 1.25(S) + 0.38$
Where S is the weight % of sulfur in the oil
Grade 5 Oil: $A = 1.25$
Grade 4 Oil: $A = 0.88$

[d] Estimated control efficiency for scrubber, 94%; ESP, 99.2%.

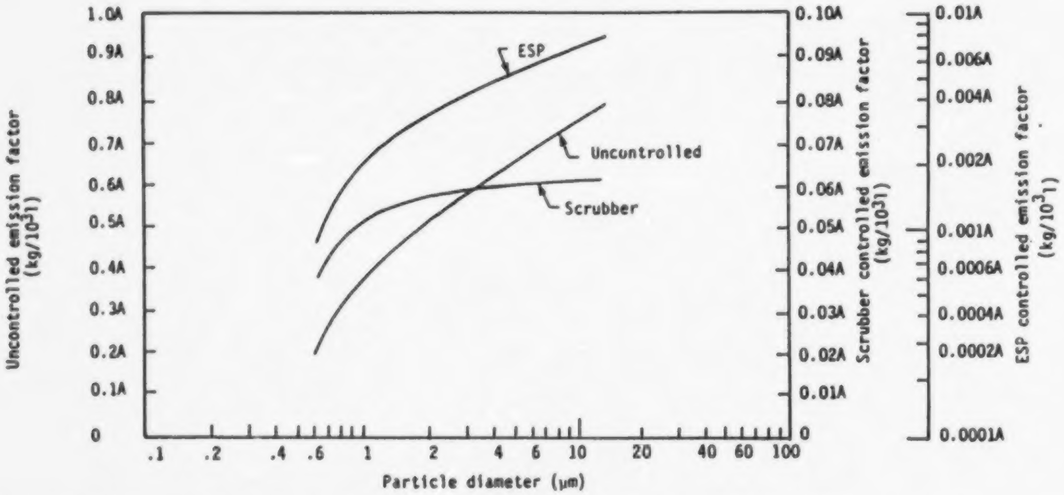

Figure 1.3-1. Cumulative size specific emission factors for utility boilers firing residual oil.

TABLE 1.3-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR INDUSTRIAL BOILERS FIRING RESIDUAL OIL[a]

EMISSION FACTOR RATING: D (uncontrolled)
E (multiple cyclone controlled)

Particle size[b] (um)	Cumulative mass % ≤ stated size		Cumulative emission factor[c] kg/10^3 l (lb/10^3 gal)	
	Uncontrolled	Multiple cyclone controlled	Uncontrolled	Multiple cyclone controlled[e]
15	91	100	0.91A (7.59A)	0.20A (1.67A)
10	86	95	0.86A (7.17A)	0.19A (1.58A)
6	77	72	0.77A (6.42A)	0.14A (1.17A)
2.5	56	22	0.56A (4.67A)	0.04A (0.33A)
1.25	39	21	0.39A (3.25A)	0.04A (0.33A)
1.00	36	21	0.36A (3.00A)	0.04A (0.33A)
0.625	30	d	0.30A (2.50A)	d
TOTAL	100	100	1A (8.34A)	0.2A (1.67A)

[a] Reference 29.

[b] Expressed as aerodynamic equivalent diameter.

[c] Particulate emission factors for residual oil combustion without emission controls are, on average, a function of fuel oil grade and sulfur content:

Grade 6 Oil: A = 1.25(S) + 0.38
Where S is the weight % of sulfur in the oil
Grade 5 Oil: A = 1.25
Grade 4 Oil: A = 0.88

[d] Insufficient data.

[e] Estimated control efficiency for multiple cyclone, 80%.

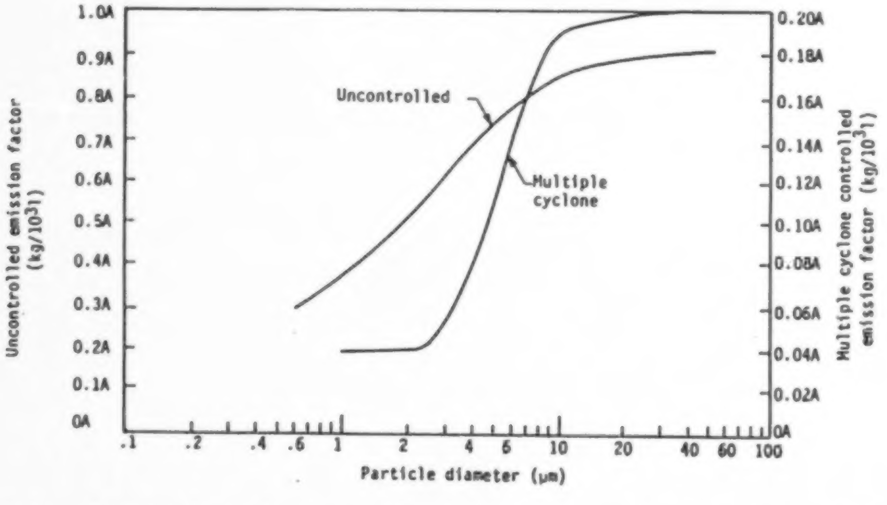

Figure 1.3-2. Cumulative size specific emission factors for industrial boilers firing residual oil.

TABLE 1.3-4. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR UNCONTROLLED INDUSTRIAL BOILERS FIRING DISTILLATE OIL[a]

EMISSION FACTOR RATING: E

Particle size[b] (um)	Cumulative mass % ≤ stated size	Cumulative emission factor kg/10^3 l (lb/10^3 gal)
	Uncontrolled	Uncontrolled
15	68	0.16 (1.33)
10	50	0.12 (1.00)
6	30	0.07 (0.58)
2.5	12	0.03 (0.25)
1.25	9	0.02 (0.17)
1.00	8	0.02 (0.17)
0.625	2	0.005 (0.04)
TOTAL	100	0.24 (2.00)

[a] Reference 29.

[b] Expressed as aerodynamic equivalent diameter.

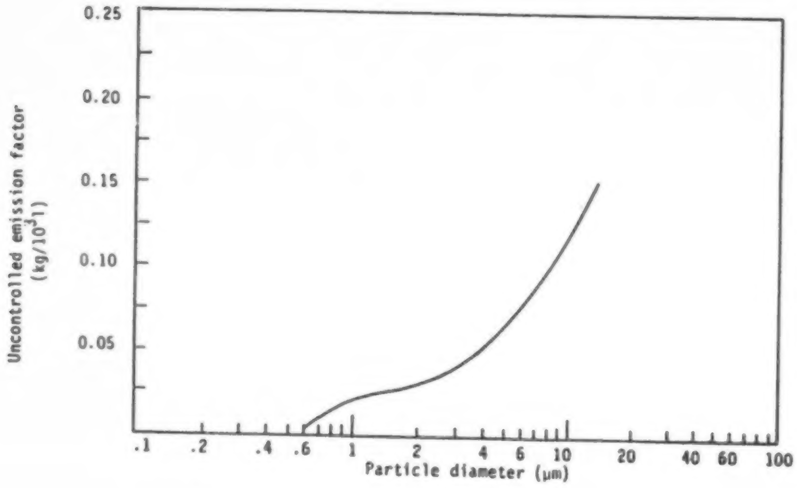

Figure 1.3-3. Cumulative size specific emission factors for uncontrolled industrial boilers firing distillate oil.

TABLE 1.3-5. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR UNCONTROLLED COMMERCIAL BOILERS BURNING RESIDUAL AND DISTILLATE OIL[a]

EMISSION FACTOR RATING: D

	Cumulative mass % ≤ stated size		Cumulative emission factor kg/10^3 l (lb/10^3 gal)	
Particle size[b] (um)	Uncontrolled with residual oil	Uncontrolled with distillate oil[c]	Uncontrolled with residual oil	Uncontrolled with distillate oil
15	78	60	0.78A (6.50A)	0.14 (1.17)
10	62	55	0.62A (5.17A)	0.13 (1.08)
6	44	49	0.44A (3.67A)	0.12 (1.00)
2.5	23	42	0.23A (1.92A)	0.10 (0.83)
1.25	16	38	0.16A (1.33A)	0.09 (0.75)
1.00	14	37	0.14A (1.17A)	0.09 (0.75)
0.625	13	35	0.13A (1.08A)	0.08 (0.67)
TOTAL	100	100	1A (8.34A)	0.24 (2.00)

[a] Reference 29.

[b] Expressed as aerodynamic equivalent diameter.

[c] Particulate emission factors for residual oil combustion without emission controls are, on average, a function of fuel oil grade and sulfur content:

Grade 6 Oil: A = 1.25 (S) + 0.38
Where S is the weight % of sulfur in the oil
Grade 5 Oil: A = 1.25
Grade 4 Oil: A = 0.88

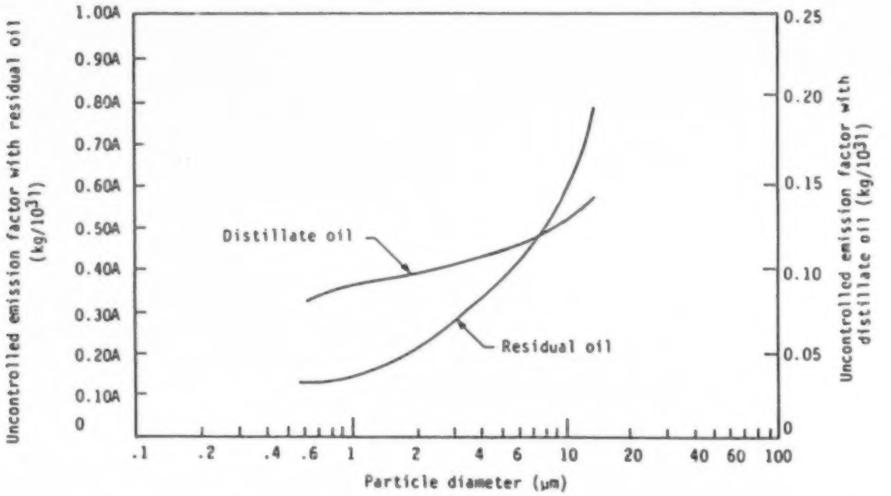

Figure 1.3-4. Cumulative size specific emission factors for uncontrolled commercial boilers burning residual and distillate oil.

Organic compounds present in the flue gas streams of boilers include aliphatic and aromatic hydrocarbons, esters, ethers, alcohols, carbonyls, carboxylic acids and polycylic organic matter. The last includes all organic matter having two or more benzene rings.

Trace elements are also emitted from the combustion of fuel oil. The quantity of trace elements emitted depends on combustion temperature, fuel feed mechanism and the composition of the fuel. The temperature determines the degree of volatilization of specific compounds contained in the fuel. The fuel feed mechanism affects the separation of emissions into bottom ash and fly ash.

If a boiler unit is operated improperly or is poorly maintained, the concentrations of carbon monoxide and VOCs may increase by several orders of magnitude.

1.3.3 Controls

The various control devices and/or techniques employed on oil fired boilers depend on the type of boiler and the pollutant being controlled. All such controls may be classified into three categories, boiler modification, fuel substitution and flue gas cleaning.

Boiler Modification [1-4,8-9,13-14,23] - Boiler modification includes any physical change in the boiler apparatus itself or in its operation. Maintenance of the burner system, for example, is important to assure proper atomization and subsequent minimization of any unburned combustibles. Periodic tuning is important in small units for maximum operating efficiency and emission control, particularly of smoke and CO. Combustion modifications, such as limited excess air firing, flue gas recirculation, staged combustion and reduced load operation, result in lowered NO_x emissions in large facilities. See Table 1.3-1 for specific reductions possible through these combustion modifications.

Fuel Substitution[3,5,12,28] - Fuel substitution, the firing of "cleaner" fuel oils, can substantially reduce emissions of a number of pollutants. Lower sulfur oils, for instance, will reduce SO_x emissions in all boilers, regardless of size or type of unit or grade of oil fired. Particulates generally will be reduced when a lighter grade of oil is fired. Nitrogen oxide emissions will be reduced by switching to either a distillate oil or a residual oil with less nitrogen. The practice of fuel substitution, however, may be limited by the ability of a given operation to fire a better grade of oil and by the cost and availability thereof.

Flue Gas Cleaning[15-16,28] - Flue gas cleaning equipment generally is employed only on large oil fired boilers. Mechanical collectors, a prevalent type of control device, are primarily useful in controlling particulates generated during soot blowing, during upset conditions, or when a very dirty heavy oil is fired. During these situations, high efficiency cyclonic collectors can effect up to 85 percent control of particulate. Under normal firing conditions, or when a clean oil is combusted, cyclonic collectors will not be nearly so effective because of the high percentage of small particles (less than 3 micrometers diameter) emitted.

Electrostatic precipitators are commonly used in oil fired power plants. Older precipitators, usually small, remove generally 40 to 60 percent of the particulate matter. Because of the low ash content of the oil, greater collection efficiency may not be required. Today, new or rebuilt electrostatic precipitators have collection efficiencies of up to 90 percent.

Scrubbing systems have been installed on oil fired boilers, especially of late, to control both sulfur oxides and particulate. These systems can achieve SO_2 removal efficiencies of 90 to 95 percent and particulate control efficiencies of 50 to 60 percent.

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1.4 NATURAL GAS COMBUSTION

1.4.1 General[1-2]

Natural gas is one of the major fuels used throughout the country. It is used mainly for power generation, for industrial process steam and heat production, and for domestic and commercial space heating. The primary component of natural gas is methane, although varying amounts of ethane and smaller amounts of nitrogen, helium and carbon dioxide are also present. Gas processing plants are required for recovery of liquefiable constitutents and removal of hydrogen sulfide (H_2S) before the gas is used (see Natural Gas Processing, Section 9.2). The average gross heating value of natural gas is approximately 9350 kilocalories per standard cubic meter (1050 British thermal units/standard cubic foot), usually varying from 8900 to 9800 kcal/scm (1000 to 1100 Btu/scf).

1.4.2 Emission And Controls[3-26]

Even though natural gas is considered to be a relatively clean fuel, some emissions can occur from the combustion reaction. For example, improper operating conditions, including poor mixing, insufficient air, etc., may cause large amounts of smoke, carbon monoxide and hydrocarbons. Moreover, because a sulfur containing mercaptan is added to natural gas to permit detection, small amounts of sulfur oxides will also be produced in the combustion process.

Nitrogen oxides are the major pollutants of concern when burning natural gas. Nitrogen oxide emissions are functions of combustion chamber temperature and combustion product cooling rate. Emission levels vary considerably with the type and size of unit and with operating conditions.

In some large boilers, several operating modifications may be used for NO_x control. Staged combustion, for example, including off-stoichiometric firing and/or two stage combustion, can reduce emissions by 5 to 50 percent.[26] In off-stoichiometric firing, also called "biased firing", some burners are operated fuel rich, some fuel lean, and others may supply air only. In two stage combustion, the burners are operated fuel rich (by introducing only 70 to 90 percent stoichiometric air), with combustion being completed by air injected above the flame zone through second stage "NO ports". In staged combustion, NO_x emissions are reduced because the bulk of combustion occurs under fuel rich conditions.

Other NO_x reducing modifications include low excess air firing and flue gas recirculation. In low excess air firing, excess air levels are kept as low as possible without producing unacceptable levels of unburned combustibles (carbon monoxide, volatile organic compounds and smoke) and/or other operating problems. This technique can reduce NO_x emissions 5 to 35 percent, primarily because of lack of oxygen during combustion. Flue gas recirculation into the primary combustion zone, because the flue gas is relatively cool and oxygen deficient, can also lower NO_x emissions 4 to 85 percent, depending on the amount of gas recirculated. Flue gas recirculation is best suited for new boilers. Retrofit application would require extensive burner modifications.

TABLE 1.4-1. UNCONTROLLED EMISSION FACTORS FOR NATURAL GAS COMBUSTION[a]

Furnace size & type (10^6 Btu/hr heat input)	Particulate[b]		Sulfur dioxide[c]		Nitrogen oxides[d]		Carbon monoxide[e]		Volatile organics			
									Nonmethane		Methane	
	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$
Utility boilers (> 100)	16 - 80	1 - 5	9.6	0.6	8800[h]	550[h]	640	40	23	1.4	4.8	0.3
Industrial boilers (10 - 100)	16 - 80	1 - 5	9.6	0.6	2240	140	560	35	44	2.8	48	3
Domestic and commercial boilers (< 10)	16 - 80	1 - 5	9.6	0.6	1600	100	320	20	84	5.3	43	2.7

[a] Expressed as weight/volume fuel fired.

[b] References 15-18.

[c] Reference 4. Based on avg. sulfur content of natural gas, 4600 $g/10^6 Nm^3$ (2000 $gr/10^6$ scf).

[d] References 4-5, 7-8, 11, 14, 18-19, 21.

[e] Expressed as NO_2. Tests indicate about 95 weight % NO_x is NO_2.

[f] References 4, 7-8, 16, 18, 22-25.

[g] References 16, 18. May increase 10 - 100 times with improper operation or maintenance.

[h] For tangentially fired units, use 4400 $kg/10^6 m^3$ (275 $lb/10^6 ft^3$). At reduced loads, multiply factor by load reduction coefficient in Figure 1.4-1. For potential NO_x reductions by combustion modification, see text. Note that NO_x reduction from these modifications will also occur at reduced load conditions.

Studies indicate that low NO_x burners (20 to 50 percent reduction) and ammonia injection (40 to 70 percent reduction) also offer NO_x emission reductions.

Combinations of the above combustion modifications may also be employed to reduce NO_x emissions further. In some boilers, for instance, NO_x reductions as high as 70 to 90 percent have been produced by employing several of these techiques simultaneously. In general, however, because the net effect of any of these combinations varies greatly, it is difficult to predict what the reductions will be in individual applications.

Although not measured, all particulate has been estimated to be less than 1 micrometer in size.[27] Emission factors for natural gas combustion are presented in Table 1.4-1, and factor ratings in Table 1.4-2.

TABLE 1.4-2. FACTOR RATINGS FOR NATURAL GAS COMBUSTION

Furnace type	Particulate	Sulfur oxides	Nitrogen oxides	Carbon monoxide	Volatile organics	
					Nonmethane	Methane
Utility boiler	B	A	A	A	C	C
Industrial boiler	B	A	A	A	C	C
Commercial boiler	B	A	A	A	D	D
Residential furnace	B	A	A	A	D	D

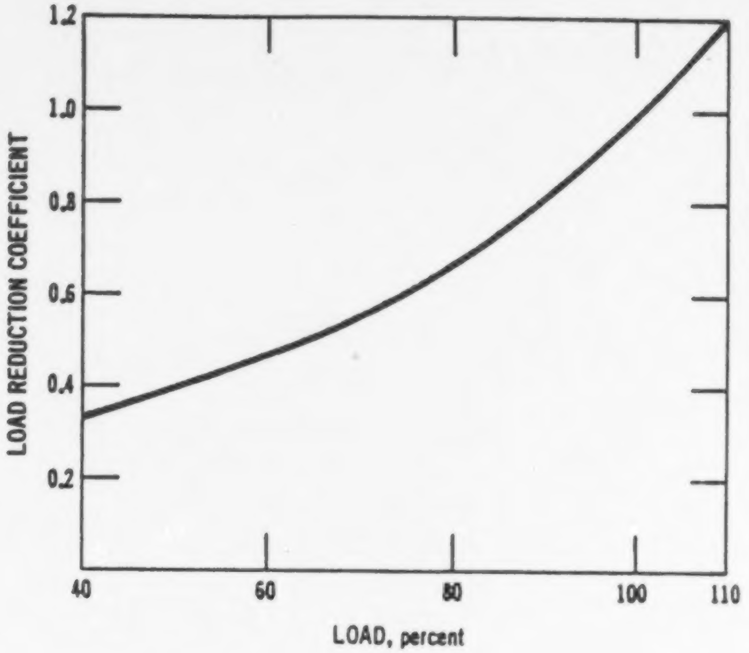

Figure 1.4-1. Load reduction coefficient as function of boiler load. (Used to determine NO_x reductions at reduced loads in large boilers.)

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6.18 AMMONIUM SULFATE MANUFACTURE

6.18.1 General[1]

Ammonium sulfate, $[NH_4]_2SO_4$, is commonly used as a fertilizer. About 90 percent of ammonium sulfate is produced by three types of facilities, caprolactam byproduct, synthetic, and coke oven byproduct plants. The remainder is produced as a byproduct of nickel manufacture from ore concentrates, methyl methacrylate manufacture, and ammonia scrubbing of tail gas at sulfuric acid plants.

During the manufacture of caprolactam, $[CH_2]_5COHN$, ammonium sulfate is produced from the oximation process stream and the rearrangement reaction stream. Synthetic ammonium sulfate is produced by the direct combination of ammonia and sulfuric acid in a reactor. Coke oven byproduct ammonium sulfate is produced by reacting ammonia recovered from coke oven offgas with sulfuric acid. Figure 6.18-1 is a process flow diagram for each of the three primary commercial processes.

After formation of the ammonium sulfate solution, operations of each process are similar. Ammonium sulfate crystals are formed by continuously circulating an ammonium sulfate liquor through an evaporator to thicken the solution. Ammonium sulfate crystals are separated from the liquor in the centrifuge. The saturated liquor is returned to the dilute ammonium sulfate brine of the evaporator. The crystals, with about 1 to 2.5 percent moisture by weight after the centrifuge, are fed to either a fluidized bed or rotary drum dryer. Fluidized bed dryers are continuously steam heated, and rotary dryers are either directly fired with oil or natural gas, or they use steam heated air. At coke oven byproduct plants, rotary drum dryers may be used in place of a centrifuge and dryer. On the filter of these dryers, a crystal layer is deposited which is removed from the drum by a scraper or a knife.

The volume of ammonium sulfate in the dryer exhaust gas varies according to production process and dryer type. A gas flow rate of 620 scm/Mg of product (20,000 scf/ton) is considered representative of a direct fired rotary drum dryer. A gas flow of 2,500 scm/Mg of product (80,000 scf/ton) is considered representative of a steam heated fluidized bed dryer. Dryer exhaust gases are passed through a particulate collection device, usually a wet scrubber, for product recovery and for pollution control.

The ammonium sulfate crystals are conveyed from the dryer to an enclosure where they are screened to product specifications, generally to coarse and fine products. The screening is enclosed to control dust in the building.

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After formation of the ammonium sulfate solution, operations of each process are similar. Ammonium sulfate crystals are formed by continuously circulating an ammonium sulfate liquor through an evaporator to thicken the solution. Ammonium sulfate crystals are separated from the liquor in the centrifuge. The saturated liquor is returned to the dilute ammonium sulfate brine of the evaporator. The crystals, with about 1 to 2.5 percent moisture by weight after the centrifuge, are fed to either a fluidized bed or rotary drum dryer. Fluidized bed dryers are continuously steam heated, and rotary dryers are either directly fired with oil or natural gas, or they use steam heated air. At coke oven byproduct plants, rotary drum dryers may be used in place of a centrifuge and dryer. On the filter of these dryers, a crystal layer is deposited which is removed from the drum by a scraper or a knife.

The volume of ammonium sulfate in the dryer exhaust gas varies according to production process and dryer type. A gas flow rate of 620 scm/Mg of product (20,000 scf/ton) is considered representative of a direct fired rotary drum dryer. A gas flow of 2,500 scm/Mg of product (80,000 scf/ton) is considered representative of a steam heated fluidized bed dryer. Dryer exhaust gases are passed through a particulate collection device, usually a wet scrubber, for product recovery and for pollution control.

The ammonium sulfate crystals are conveyed from the dryer to an enclosure where they are screened to product specifications, generally to coarse and fine products. The screening is enclosed to control dust in the building.

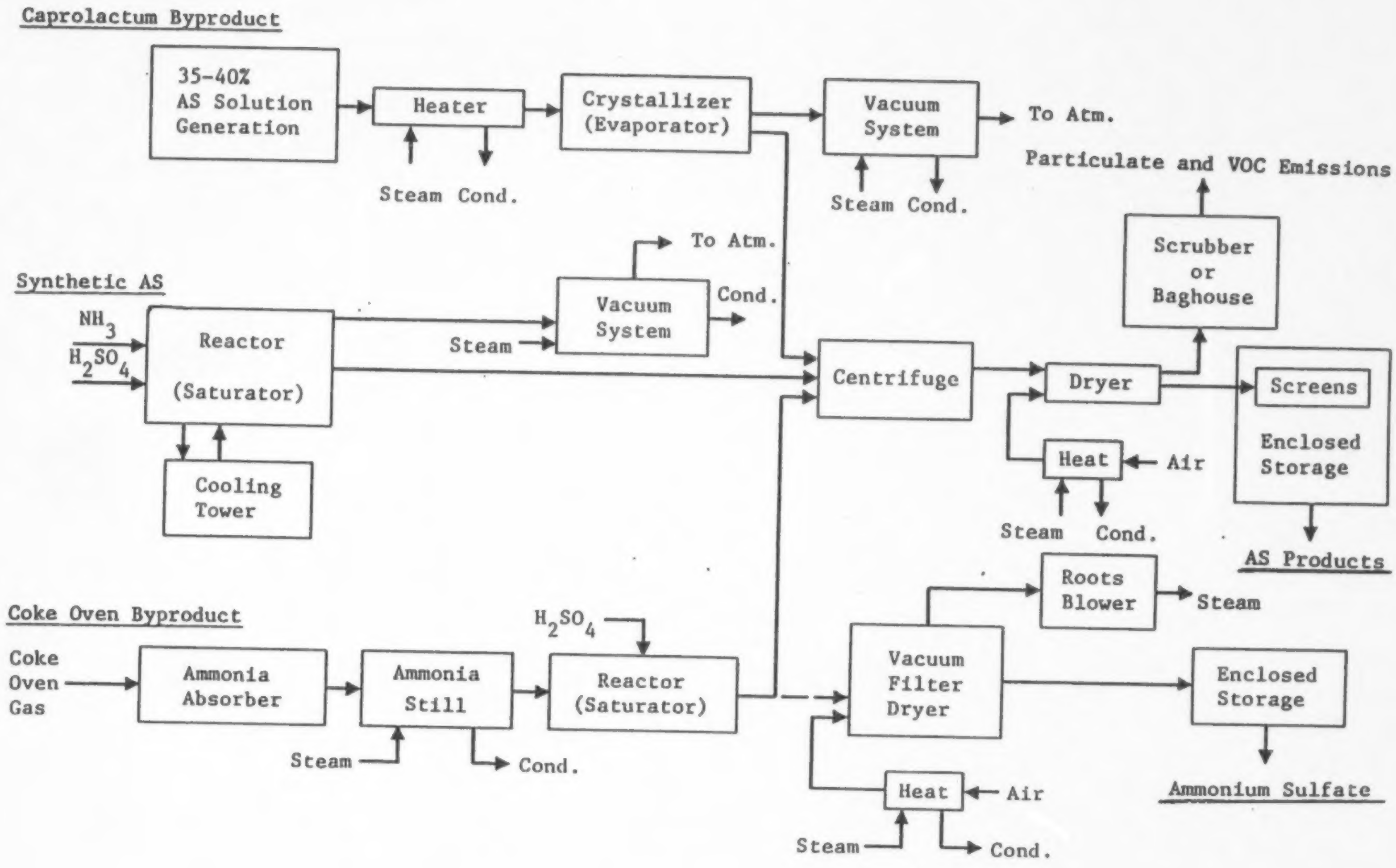

Caprolactum Byproduct
35-40% AS Solution Generation
Heater
Steam
Cond.
Crystallizer (Evaporator)
Vacuum System
Steam
Cond.
To Atm.
Synthetic AS
NH_3
H_2SO_4
Reactor (Saturator)
Cooling Tower
Steam
Vacuum System
To Atm.
Cond.
Centrifuge
Dryer
Heat
Air
Steam
Cond.
Scrubber or Baghouse
Particulate and VOC Emissions
Screens
Enclosed Storage
AS Products
Coke Oven Byproduct
Coke Oven Gas
Ammonia Absorber
Ammonia Still
Steam
Cond.
H_2SO_4
Reactor (Saturator)
Vacuum Filter Dryer
Heat
Air
Steam
Cond.
Roots Blower
Steam
Enclosed Storage
Ammonium Sulfate

Figure 6.18-1. Diagram of Ammonium Sulfate (AS) processes.

6.18.2 Emissions and Controls

Ammonium sulfate particulate is the principal pollutant emitted to the atmosphere from the manufacturing plants, nearly all of it being contained in the gaseous exhaust of the dryers. Other plant processes, such as evaporation, screening, and materials handling, are not significant sources of emissions.

The particulate emission rate of a dryer depends on the gas velocity and the particle size distribution. Since gas velocity varies according to the dryer type, emission rates also vary. Generally, the gas velocity of fluidized bed dryers is higher than for most rotary drum dryers, and particulate emission rates are also higher. The smaller the particle, the easier it is removed by the gas stream of either type of dryer.

At caprolactam byproduct plants, volatile organic compounds (VOC) are emitted from the dryers. Emissions of caprolactam vapor are at least two orders of magnitude lower than the particulate emissions.

Wet scrubbers, such as venturi and centrifuge, are most suitable for reducing particulate emissions from the dryers. Wet scrubbers use process streams as the scrubbing liquid. This allows the collected particulate to be recycled easily to the production system.

Table 6.18-1 shows the uncontrolled and controlled emission factors for the various dryer types. The VOC emissions shown in Table 6.18-1 apply only to caprolactam byproduct plants which may use either a fluidized bed or rotary drum dryer.

TABLE 6.18-1. EMISSION FACTORS FOR AMMONIUM SULFATE MANUFACTURE[a]

EMISSION FACTOR RATING: B

	Particulates		Volatile Organic Compounds[b]	
Dryer Type & Controls	kg/Mg	lb/ton	kg/Mg	lb/ton
Rotary dryers				
Uncontrolled	23	46	0.74	1.48
Wet scrubber	0.12	0.24	0.11	0.22
Fluidized bed dryers				
Uncontrolled	109	218	0.74	1.48
Wet scrubber	0.14	0.28	0.11	0.22

[a] Expressed as emissions by weight per unit of ammonium sulfate production by weight.

[b] VOC emissions occur only at caprolactam plants using either type of dryer. The emissions are caprolactam vapor.

Reference for Section 6.18

1. Ammonium Sulfate Manufacture - Background Information for Proposed Emission Standards, EPA-450/3-79-034a, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1979.

7.2 COKE MANUFACTURING

7.2.1 Process Description

Metallurgical coke is manufactured by destructive distillation of coal in a byproduct coke oven battery. The distillation, termed "coking", is accomplished in a series of ovens in the absence of oxygen. Volatile compounds are driven from the coal, collected from each oven, and processed in an adjacent plant for recovery of combustible gases and other coal byproducts. Virtually all metallurgical coke is produced by this process, termed the "byproduct" method. Metallurgical coke is used in blast furnaces for production of iron.

Coke is produced in narrow, slot type ovens constructed of silica brick. A coke oven battery may have a series of 10 to 100 individual ovens, with a heating flue between each oven pair. Ovens are charged with pulverized coal, through ports in the oven top, by a larry car traveling on tracks along the top of each battery. After charging, the ports are sealed, and the coking process begins. Combustion of gases in burners in the flues between the ovens provides heat for the process. Coke oven gas from the byproduct recovery plant is the common fuel for underfiring the ovens at most plants, but blast furnace gas and, infrequently, natural gas may also be used.

After a coking time typically between 12 and 20 hours, almost all volatile matter is driven from the coal mass, and the coke is formed. Maximum temperature at the center of the coke mass is usually 1100 to 1150°C (2000 to 2100°F).

After coking, machinery located on tracks on each side of the battery removes the vertical door on each end of an oven, and a long ram pushes the coke from the oven into a rail quench car, whence it goes to a quench tower, where several thousand gallons of water are sprayed onto the coke mass to cool it. The car then discharges the coke onto a wharf along the battery for further cooling and drainage of water. From here, coke is screened and sent to the blast furnace or to storage in outdoor piles.

After the coke is pushed from an oven, the doors are cleaned and repositioned, and the oven is then ready to receive another charge of coal. Figure 7.2-1 is a diagram of a typical byproduct coke process.

During the coking cycle, volatile matter driven from the coal mass is collected by offtakes located at one or both ends of the oven. A common collector main transports the gases from each oven to the byproduct recovery plant. Here, coke oven gas is separated, cleaned and returned to heat the ovens. Only 40 percent of recovered coke oven gas is required for underfiring, and the remainder is used throughout the steel plant. Other coal byproducts also are recovered in the byproduct plant for reuse, sale or disposal.

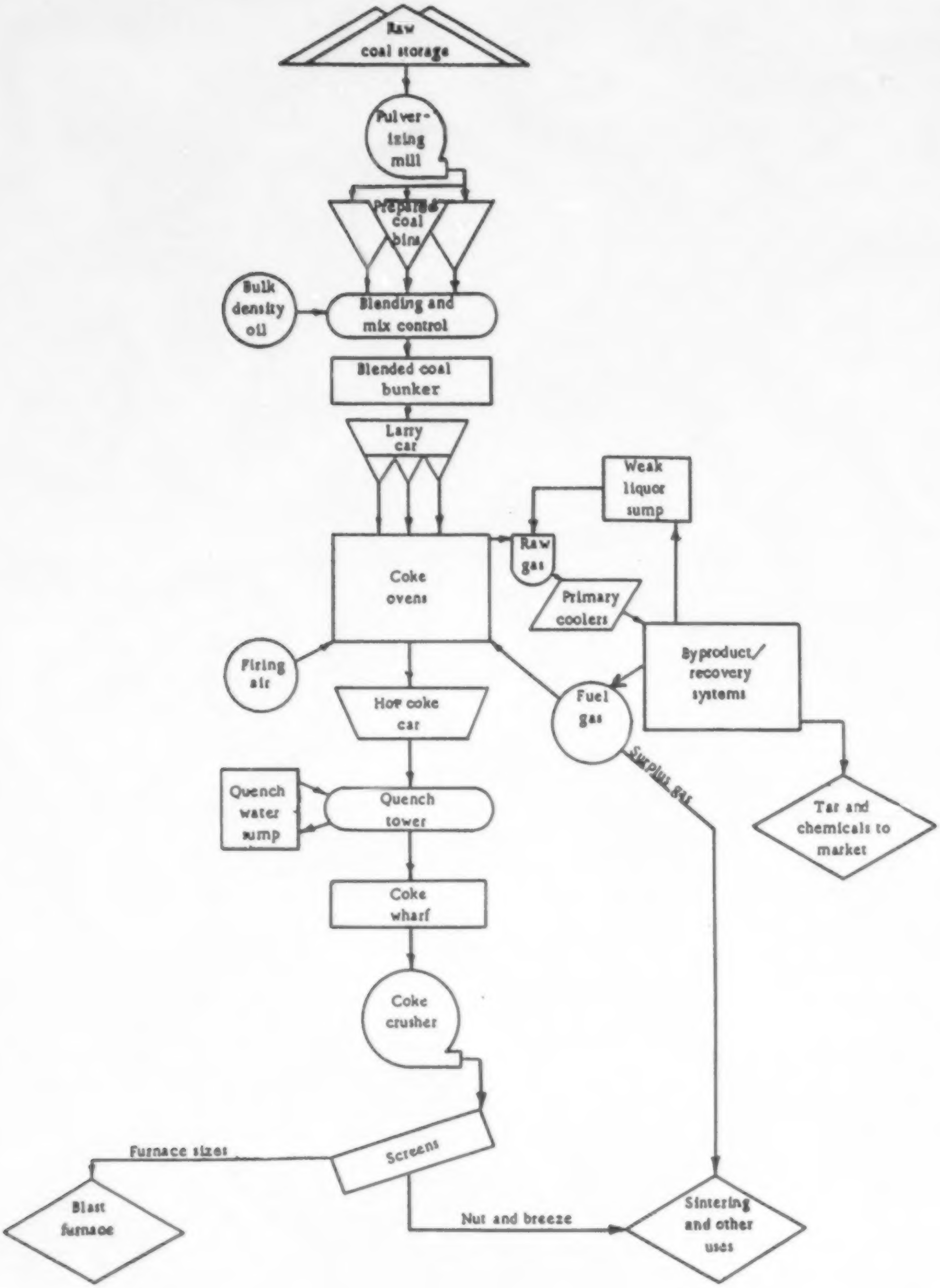

Raw coal storage
Pulverizing mill
Prepared coal bins
Bulk density oil
Blending and mix control
Blended coal bunker
Larry car
Weak liquor sump
Raw gas
Coke ovens
Primary coolers
Byproduct/ recovery systems
Firing air
Hot coke car
Fuel gas
Surplus gas
Tar and chemicals to market
Quench water sump
Quench tower
Coke wharf
Coke crusher
Screens
Furnace sizes
Blast furnace
Nut and breeze
Sintering and other uses

Figure 7.2-1. The major steps in the carbonization of coal with the byproduct process.

7.2.2 Emissions And Controls

Particulate, volatile organic compounds, carbon monoxide and other emissions originate from several byproduct coking operations: (1) coal preparation, (2) coal preheating (if used), (3) charging coal into ovens incandescent with heat, (4) oven leakage during the coking period, (5) pushing the coke out of the ovens, (6) quenching the hot coke and (7) underfire combustion stacks. Gaseous emissions collected from the ovens during the coking process in the byproduct plant are subjected to various operations for separating ammonia, coke oven gas, tar, phenol, light oil (benzene, toluene, xylene) and pyridine. These unit operations are potential sources of volatile organic compound emissions.

Coal preparation consists of pulverizing, screening, blending of several coal types, and adding oil or water for bulk density control. Particulate emissions are sometimes controlled by evacuated or unevacuated enclosures. A few domestic plants heat coal to about 260°C (500°F) before charging, using a flash drying column heated by combustion of coke oven or natural gas. The air steam that conveys the coal through the drying column usually is passed through conventional wet scrubbers for particulate removal before discharge to the atmosphere.

Oven charging can produce emissions of particulate matter and volatile organic compounds from coal decomposition. The stage, or sequential, charging techniques used on virtually all batteries draw most charging emissions into the battery collector main and on to the byproduct plant. During the coking cycle, volatile organic emissions from the thermal distillation process occasionally leak to the atmosphere through poorly sealed doors, charge lids and offtake caps, and through cracks which may develop in oven brickwork, the offtakes and collector mains. Door leaks are controlled by diligent door cleaning and maintenance, rebuilding of doors, and in some plants, by manual application of lute (seal) material. Charge lid and offtake leaks are controlled by an effective patching and luting program.

Pushing coke into the quench car is another major source of particulate emissions, and if the coke mass is not fully coked, also of volatile organic compounds and combustion products. Most batteries use pushing emission controls such as hooded, mobile scrubber cars; shed enclosures evacuated to a gas cleaning device; or traveling hoods with a fixed duct leading to a stationary gas cleaner. The quench tower activity emits particulate from the coke mass, and dissolved solids from the quench water may become entrained in the steam plume rising from the tower. Trace organic compounds also may be present.

The gas combustion in the battery flues produces emissions through the underfire or combustion stack. If coke oven gas is not desulfurized, sulfur oxide emissions accompany the particulate and combustion emissions. If oven wall brickwork is damaged, coal fines and coking decomposition products from a recently charged oven may leak into the waste combustion gases. Figure 7.2-2 portrays major air pollution sources from a typical coke oven battery.

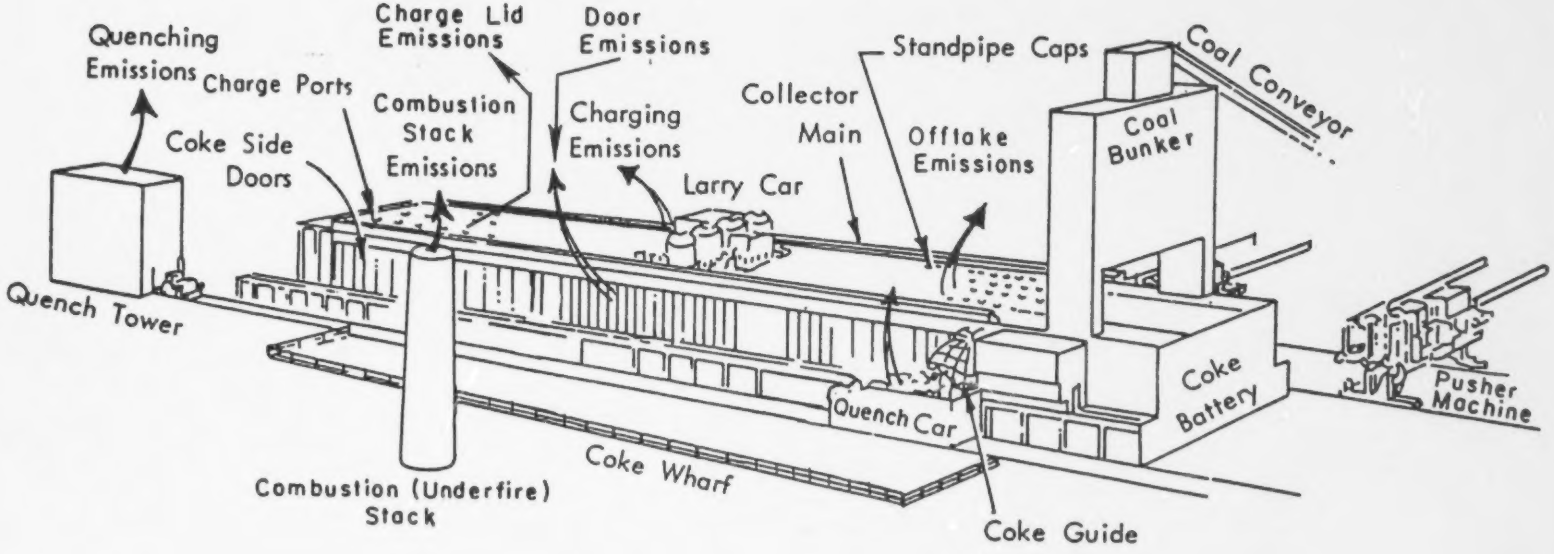
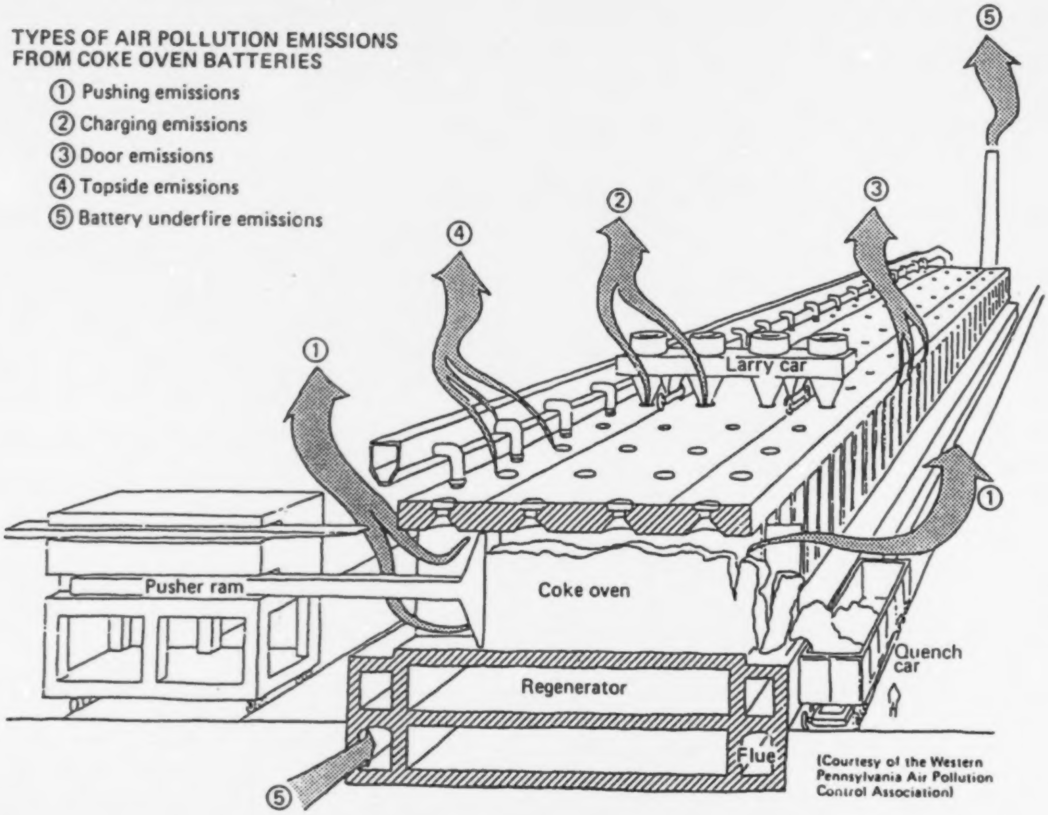

Quenching Emissions
Charge Ports
Charge Lid Emissions
Door Emissions
Standpipe Caps
Coal Conveyor
Coke Side Doors
Combustion Stack Emissions
Charging Emissions
Collector Main
Offtake Emissions
Coal Bunker
Larry Car
Quench Tower
Coke Battery
Pusher Machine
Quench Car
Combustion (Underfire) Stack
Coke Wharf
Coke Guide

Figure 7.2-2. Byproduct coke oven battery, with major emission points shown.

Associated with the byproduct coke production are open source fugitive dust operations from material handling. These operations consist of unloading, storing grinding and sizing of coal; and screening, crushing, storing and loading of coke. Fugitive emissions may also result from vehicles traveling on paved and unpaved surfaces. The emission factors available for coking operations for total particulate, sulfur dioxide, carbon monoxide, volatile organic compounds, nitrogen oxides and ammonia are given in Table 7.2-1. Table 7.2-2 gives available size specific emission factors. Figures 7.2-3 through 7.2-13 present emission factor data by particle size. Extensive information on the data used to develop the particulate emission factors can be found in Reference 1.


TYPES OF AIR POLLUTION EMISSIONS FROM COKE OVEN BATTERIES
① Pushing emissions
② Charging emissions
③ Door emissions
④ Topside emissions
⑤ Battery underfire emissions
⑤
③
②
④
①
Larry car
①
Pusher ram
Coke oven
Regenerator
Quench car
Flue
⑤

(Courtesy of the Western Pennsylvania Air Pollution Control Association)

TABLE 7.2-1. EMISSION FACTORS FOR COKE MANUFACTURING[a]

EMISSION FACTOR RATING: D (except Particulate)

Type of operation	Particulate Emission Factor Rating[b]	Particulate[b]		Sulfur dioxide[c]		Carbon monoxide[c]		Volatile organics[c,d]		Nitrogen oxides[c]		Ammonia[c]	
		kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Coal crushing with cyclone	D	0.055	0.11	-	-	-	-	-	-	-	-	-	-
Coal preheating													
Uncontrolled[e]	C	1.75	3.50	-	-	-	-	-	-	-	-	-	-
With scrubber	C	0.125	0.25	-	-	-	-	-	-	-	-	-	-
With wet ESP	C	0.006	0.012	-	-	-	-	-	-	-	-	-	-
Wet coal charging[f]													
Larry car													
Uncontrolled	E	0.24	0.48	0.01	0.02	0.3	0.6	1.25	2.5	0.015	0.03	0.01	0.02
With sequential charging	E	0.008	0.016	-	-	-	-	-	-	-	-	-	-
With scrubber	E	0.007	0.014	-	-	-	-	-	-	-	-	-	-
Door leak													
Uncontrolled	D	0.27	0.54	-	-	0.3	0.6	0.75	1.5	0.005	0.01	0.03	0.06
Coke pushing													
Uncontrolled	B	0.58	1.15	-	-	0.035	0.07	0.1	0.2	-	-	0.05	0.1
With ESP[g]	C	0.225	0.45	-	-	-	-	-	-	-	-	-	-
With venturi scrubber[h]	D	0.09	0.18	-	-	-	-	-	-	-	-	-	-
With baghouse[h]	D	0.045	0.09	-	-	-	-	-	-	-	-	-	-
With mobile scrubber car[j]	C	0.036	0.072	-	-	-	-	-	-	-	-	-	-

TABLE 7.2-1 (cont.). EMISSION FACTORS FOR COKE MANUFACTURING[a]

Type of operation	Particulate Emission Factor Rating[b]	Particulate[b]		Sulfur dioxide[c]		Carbon monoxide[c]		Volatile organics[c,d]		Nitrogen oxides[c]		Ammonia[c]	
		kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Quenching													
Uncontrolled													
Dirty water[k]	D	2.62	5.24	-	-	-	-	-	-	-	-	-	-
Clean water[m]	D	0.57	1.13	-	-	-	-	-	-	-	-	-	-
With baffles													
Dirty water[k]	B	0.65	1.30	-	-	-	-	-	-	-	-	-	-
Clean water[m]	B	0.27	0.54	-	-	-	-	-	-	-	-	-	-
Combustion stack													
Uncontrolled (COG)	A	0.234	0.47	2.0[n]	4.0[n]	-	-	-	-	-	-	-	-
Uncontrolled (BFG)	A	0.085	0.17	-	-	-	-	-	-	-	-	-	-
With ESP (COG)	D	0.046	0.091	-	-	-	-	-	-	-	-	-	-
With baghouse (COG)	D	0.055	0.11	-	-	-	-	-	-	-	-	-	-
Coke handling													
With cyclone[p]	D	0.003	0.006	-	-	-	-	-	-	-	-	-	-
Combined operations[q]	D	-	-	-	-	-	-	-	-	-	-	-	-

[a] Expressed as units/unit of coal charged. Dash = no data. ESP = electrostatic precipitator. COG = coke oven gas. BFG = blast furnace gas.

[b] Reference 1.

[c] References 2-3.

[d] Expressed as methane.

[e] Exhaust gas discharged from series of primary and secondary cyclones used to separate flash dried coal from hot gas.

[f] Charged coal has not been dried.

[g] Emissions captured by coke side shed.

[h] Emissions captured by traveling hood.

[j] Emissions captured by quench car enclosure.

[k] Dirty water $\geq$5000 mg/l total dissolved solids.

[m] Clean water $\leq$1500 mg/l total dissolved solids.

[n] Reference 4. Factor for SO_2 is based on these representative conditions: (1) sulfur content of coal charged to oven is 0.8 weight %; (2) about 33 weight % of total sulfur in coal charged to oven is transferred to coke oven gas; (3) about 40% of coke oven gas is burned during underfiring operation, and about 60% is used in other operations where the rest of the SO_2 [3 kg/Mg (6 lb/ton) of coal charged] is discharged; (4) gas used in underfiring has not been desulfurized.

[p] Defined as crushing and screening.

[q] References 19-20. Uncontrolled lead emissions are 0.00018 kg/Mg (0.00035 lb/ton).

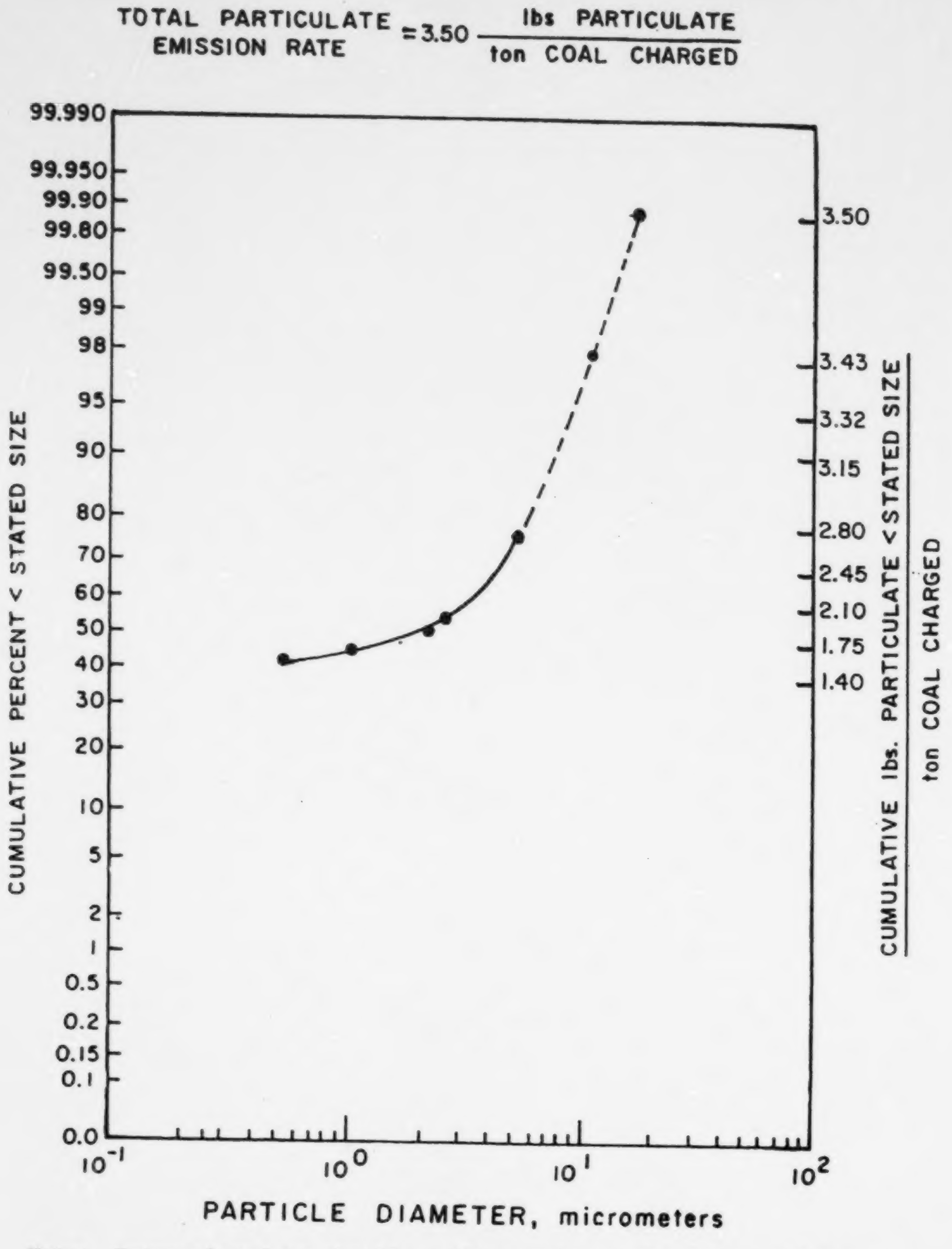
TABLE 7.2-2. SIZE SPECIFIC EMISSION FACTORS FOR COKE MANUFACTURING

Process	Particulate emission factor rating	Particle size (µm)	Cumulative mass % ≤ stated size	Cumulative mass emission factors		Reference source number
				kg/Mg	lb/ton	
Coal preheating Uncontrolled	D	0.5	44	0.8	1.5	6
		1.0	48.5	0.8	1.7	
		2.0	55	1.0	1.9	
		2.5	59.5	1.0	2.1	
		5.0	79.5	1.4	2.8	
		10.0	97.5	1.7	3.4	
		15.0	99.9	1.7	3.5	
			100	1.7	3.5	
Controlled with venturi scrubber	D	0.5	78	0.10	0.20	6
		1.0	80	0.10	0.20	
		2.0	83	0.10	0.21	
		2.5	84	0.11	0.21	
		5.0	88	0.11	0.22	
		10.0	94	0.12	0.24	
		15.0	96.5	0.12	0.24	
			100	0.12	0.25	
Coal charging Sequential or stage	E	0.5	13.5	0.001	0.002	7
		1.0	25.2	0.002	0.004	
		2.0	33.6	0.003	0.005	
		2.5	39.1	0.003	0.006	
		5.0	45.8	0.004	0.007	
		10.0	48.9	0.004	0.008	
		15.0	49.0	0.004	0.008	
			100	0.008	0.016	
Coke pushing Uncontrolled	D	0.5	3.1	0.02	0.04	8-13
		1.0	7.7	0.04	0.09	
		2.0	14.8	0.09	0.17	
		2.5	16.7	0.10	0.19	
		5.0	26.6	0.15	0.30	
		10.0	43.3	0.25	0.50	
		15.0	50.0	0.29	0.58	
			100	0.58	1.15	
Controlled with Venturi scrubber	D	0.5	24	0.02	0.04	8,10
		1.0	47	0.04	0.08	
		2.0	66.5	0.06	0.12	
		2.5	73.5	0.07	0.13	
		5.0	75	0.07	0.13	
		10.0	87	0.08	0.16	
		15.0	92	0.08	0.17	
			100	0.09	0.18	

(continued)

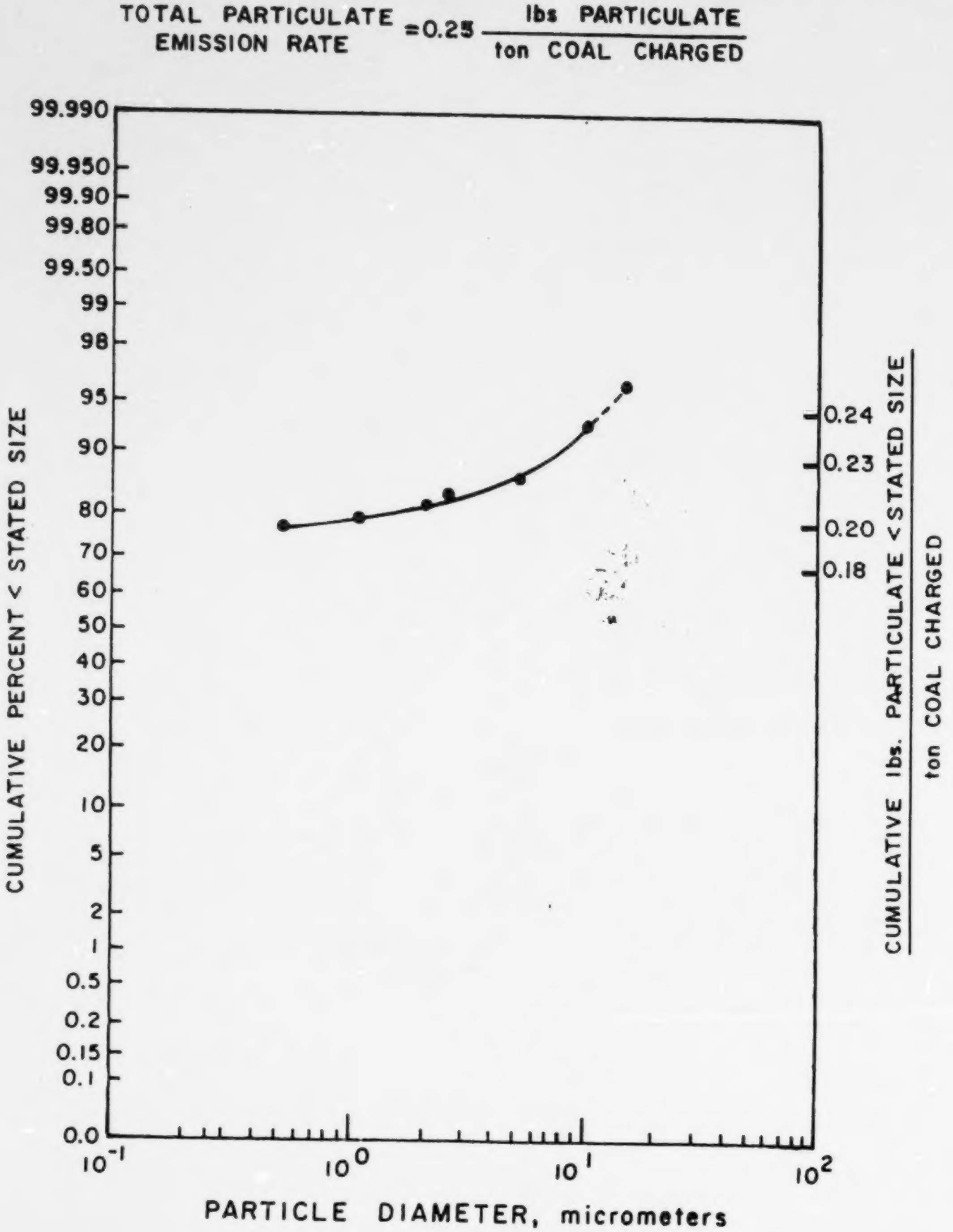
TABLE 7.2-2 (continued)

Process	Particulate emission factor rating	Particle size (µm)	Cumulative mass % ≤ stated size	Cumulative mass emission factors		Reference source number
				kg/Mg	lb/ton	
Mobile scrubber car	D	1.0	28.0	0.010	0.020	14
		2.0	29.5	0.011	0.021	
		2.5	30.0	0.011	0.022	
		5.0	30.0	0.011	0.022	
		10.0	32.0	0.012	0.024	
		15.0	35.0	0.013	0.023	
			100	0.036	0.072	
Quenching Uncontrolled (dirty water)	D	1.0	13.8	0.36	0.72	15
		2.5	19.3	0.51	1.01	
		5.0	21.4	0.56	1.12	
		10.0	22.8	0.60	1.19	
		15.0	26.4	0.69	1.38	
			100	2.62	5.24	
Uncontrolled (clean water)	B	1.0	4.0	0.02	0.05	15
		2.5	11.1	0.06	0.13	
		5.0	19.1	0.11	0.22	
		10.0	30.1	0.17	0.34	
		15.0	37.4	0.21	0.42	
			100	0.57	1.13	
With baffles (dirty water)	D	1.0	8.5	0.06	0.11	15
		2.5	20.4	0.13	0.27	
		5.0	24.8	0.16	0.32	
		10.0	32.3	0.21	0.42	
		15.0	49.8	0.32	0.65	
			100	0.65	1.30	
With baffles (clean water)	D	1.0	1.2	0.003	0.006	15
		2.5	6.0	0.02	0.03	
		5.0	7.0	0.02	0.04	
		10.0	9.8	0.03	0.05	
		15.0	15.1	0.04	0.08	
			100	0.27	0.54	
Combustion stack Uncontrolled	D	1.0	77.4	0.18	0.36	16-18
		2.0	85.7	0.20	0.40	
		2.5	93.5	0.22	0.44	
		5.0	95.8	0.22	0.45	
		10.0	95.9	0.22	0.45	
		15.0	96	0.22	0.45	
			100	0.23	0.47	



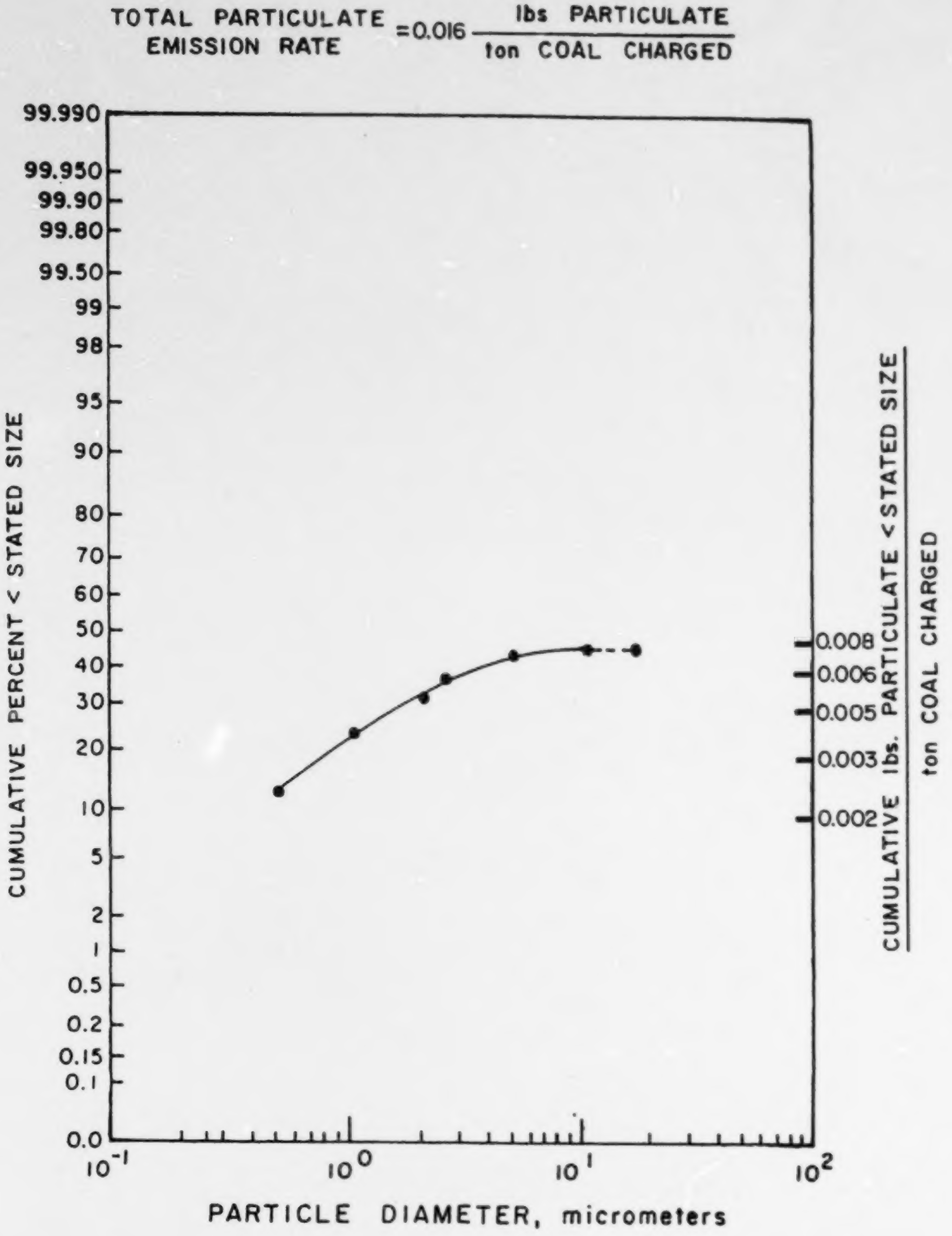
Note: Extrapolated to the 15 μm size, using engineering estimates.

Figure 7.2-3. Coal preheating (uncontrolled).



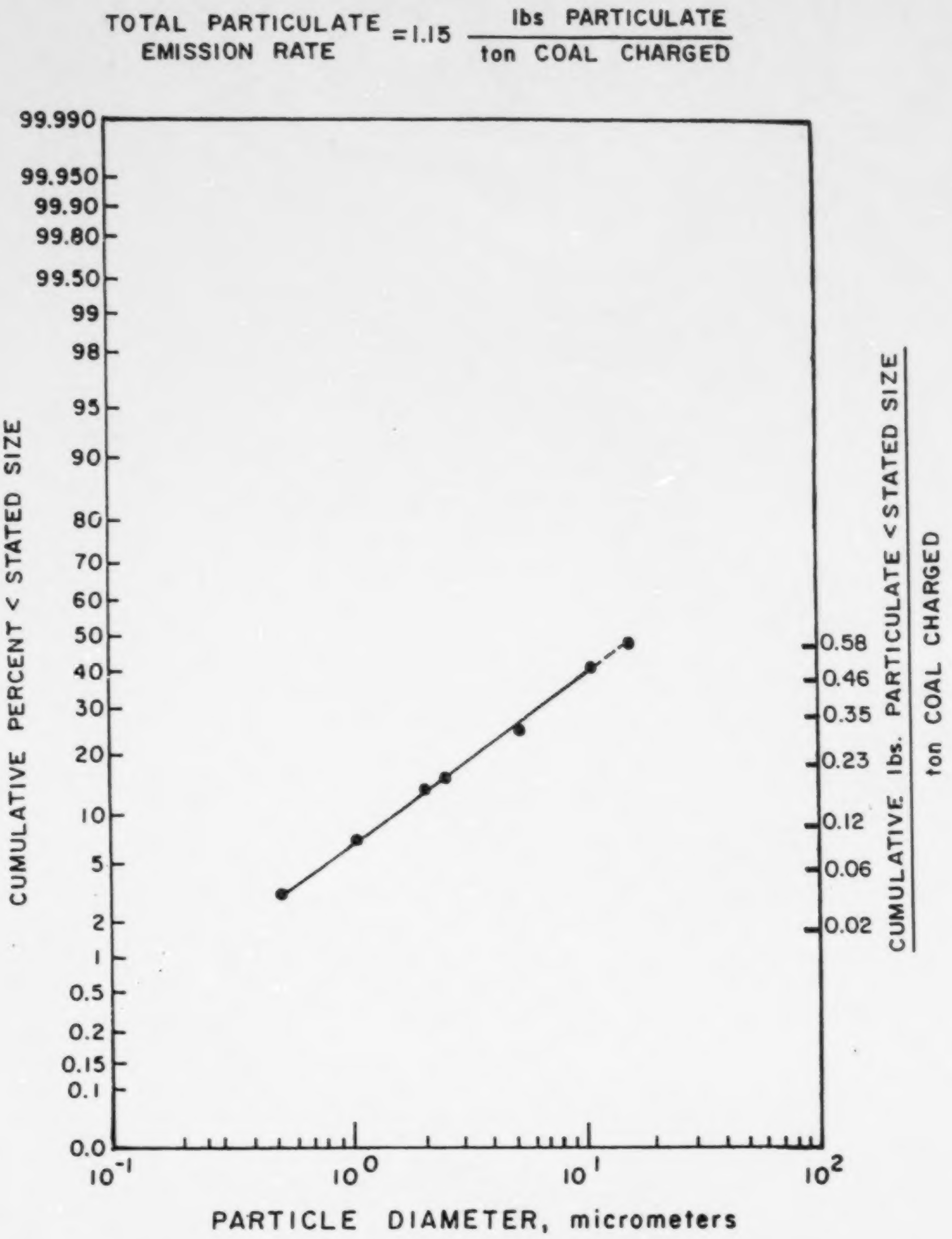
Note: Extrapolated to the 15 μm size, using engineering estimates.

Figure 7.2-4. Coal preheating (controlled with scrubber).



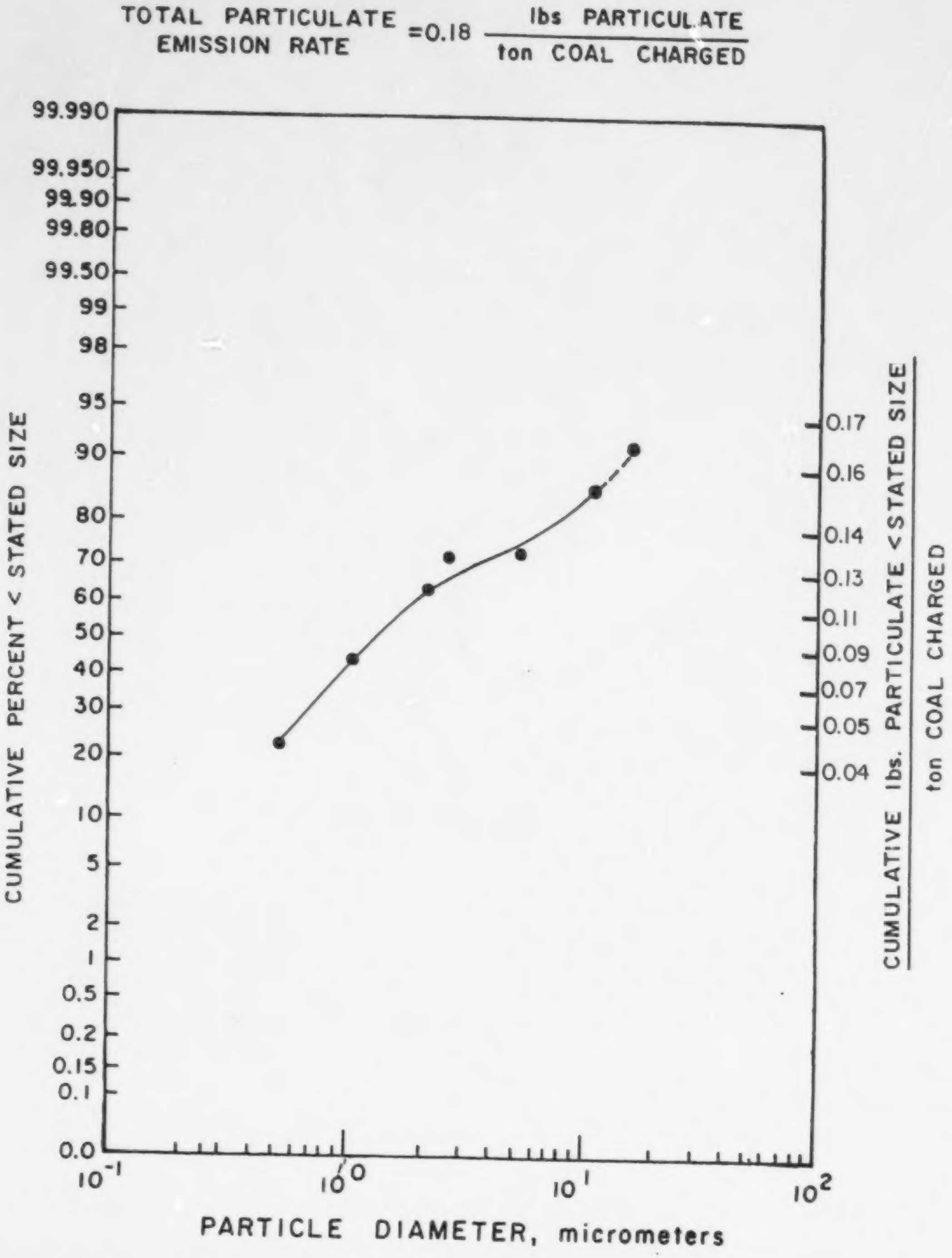
Note: Extrapolated to the 15 μm size, using engineering estimates.

Figure 7.2-5. Coal charging (sequential) average of 2 tests.



Note: Extrapolated to the 15 μm size, using engineering estimates.

Figure 7.2-6. Pushing (uncontrolled) average of 6 sites.



Note: Extrapolated to the 15 µm size, using engineering estimates.

Figure 7.2-7. Pushing (controlled with scrubber) average of 2 sites.

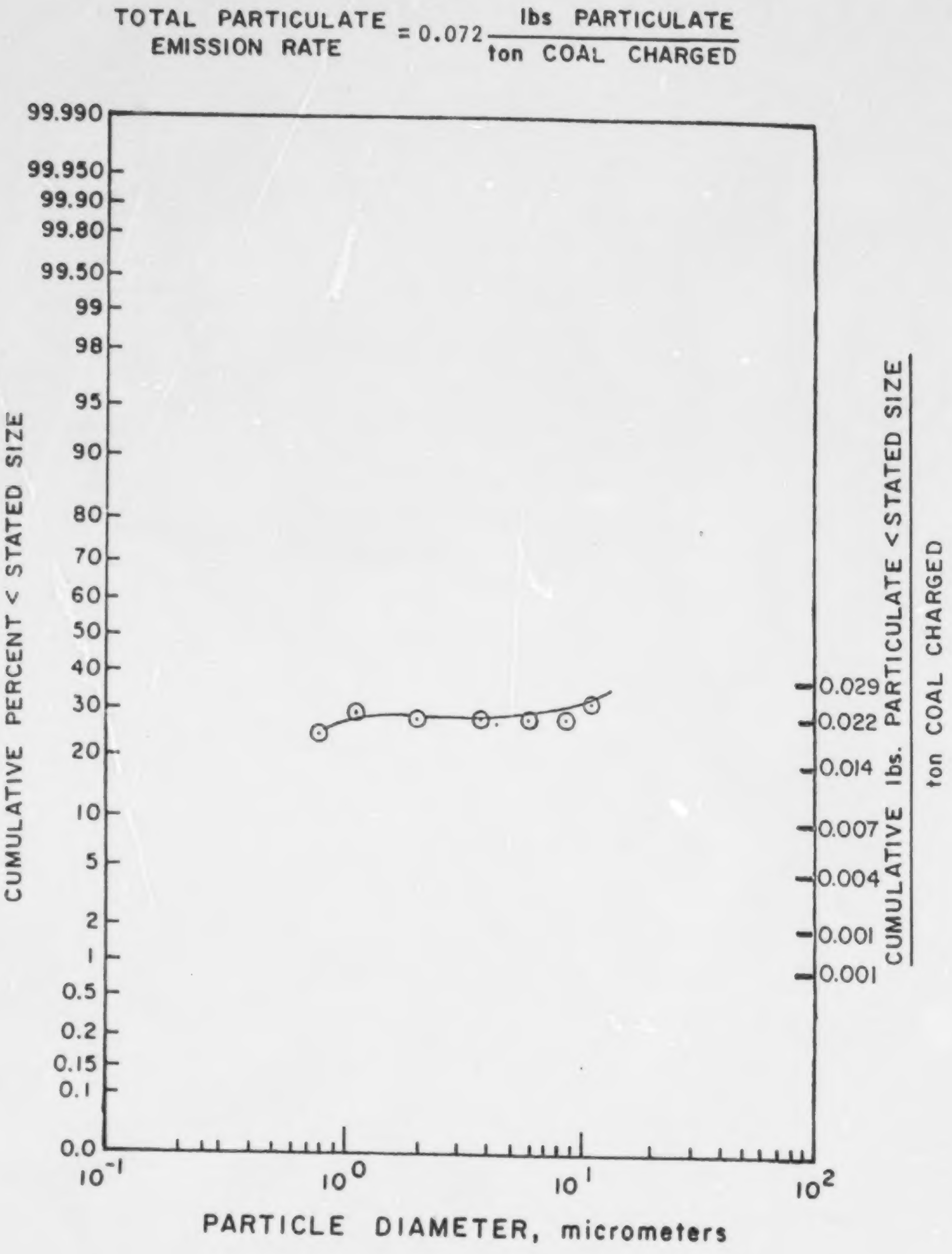


Figure 7.2-8. Mobile scrubber cars.

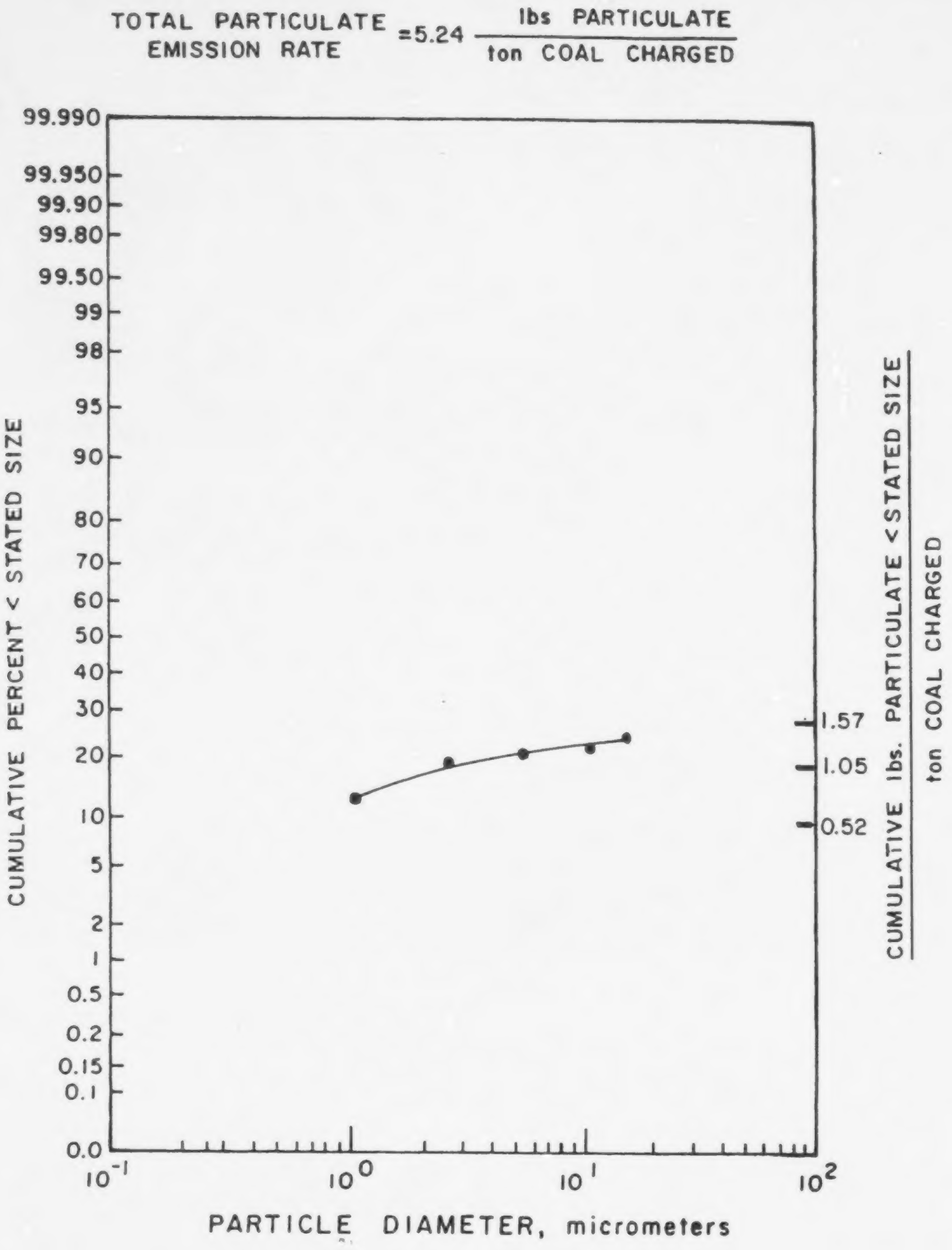


Figure 7.2-9. Quenching (uncontrolled) dirty water >5,000 mg/L TDS.

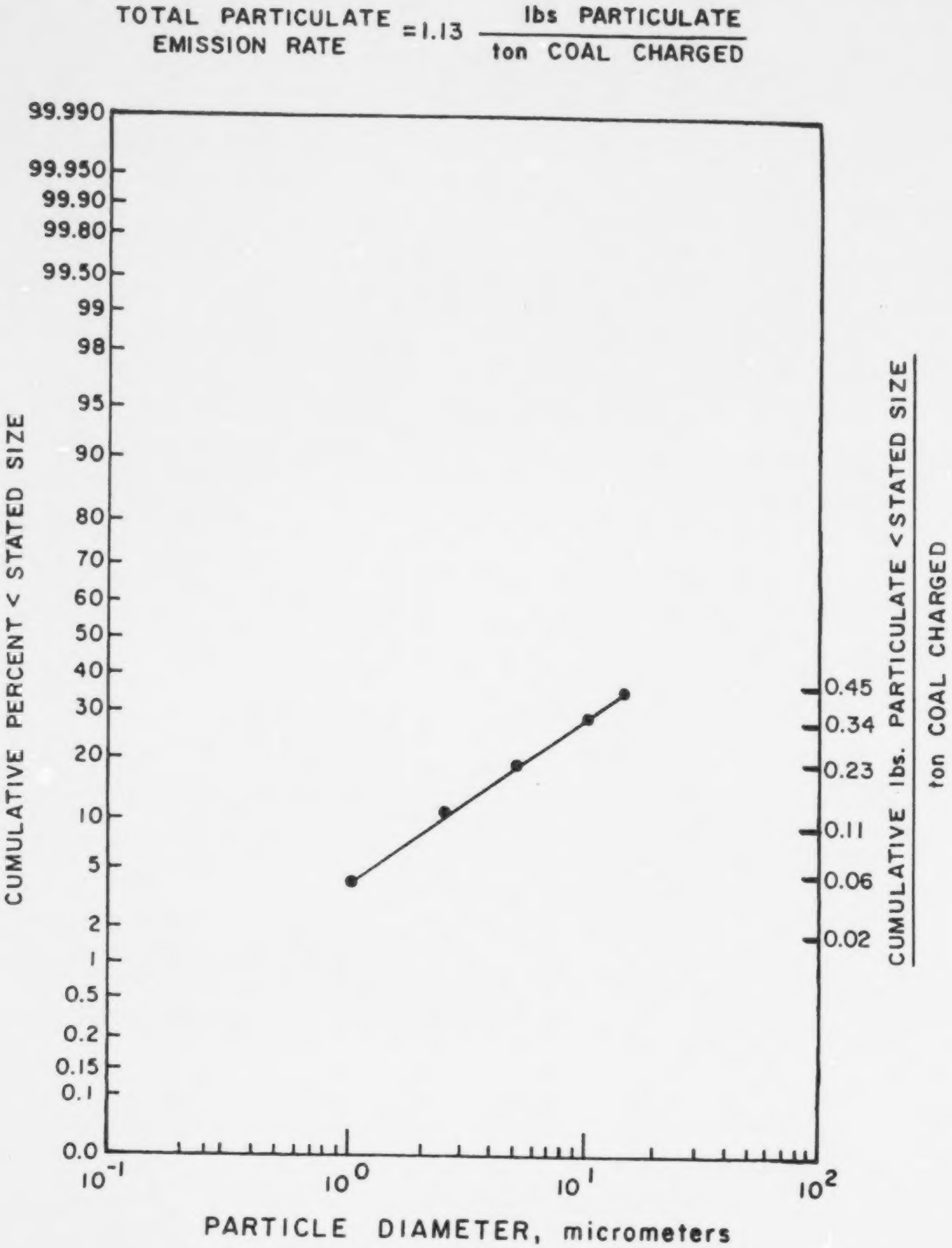


Figure 7.2-10. Quenching (uncontrolled) clean water <1,500 mg/L TDS.

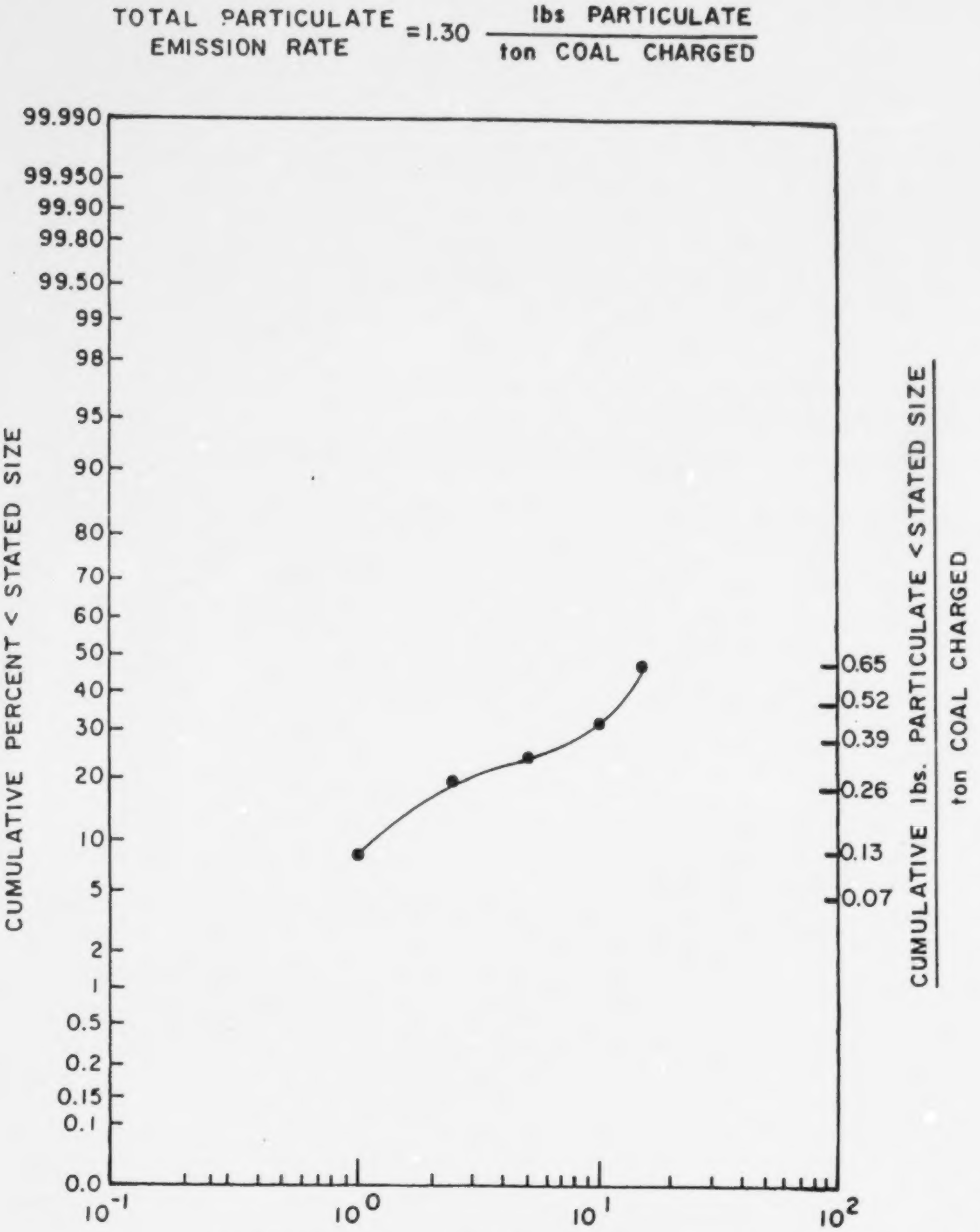


Figure 7.2-11. Quenching (controlled with baffles) dirty water >5,000 mg/L TDS.

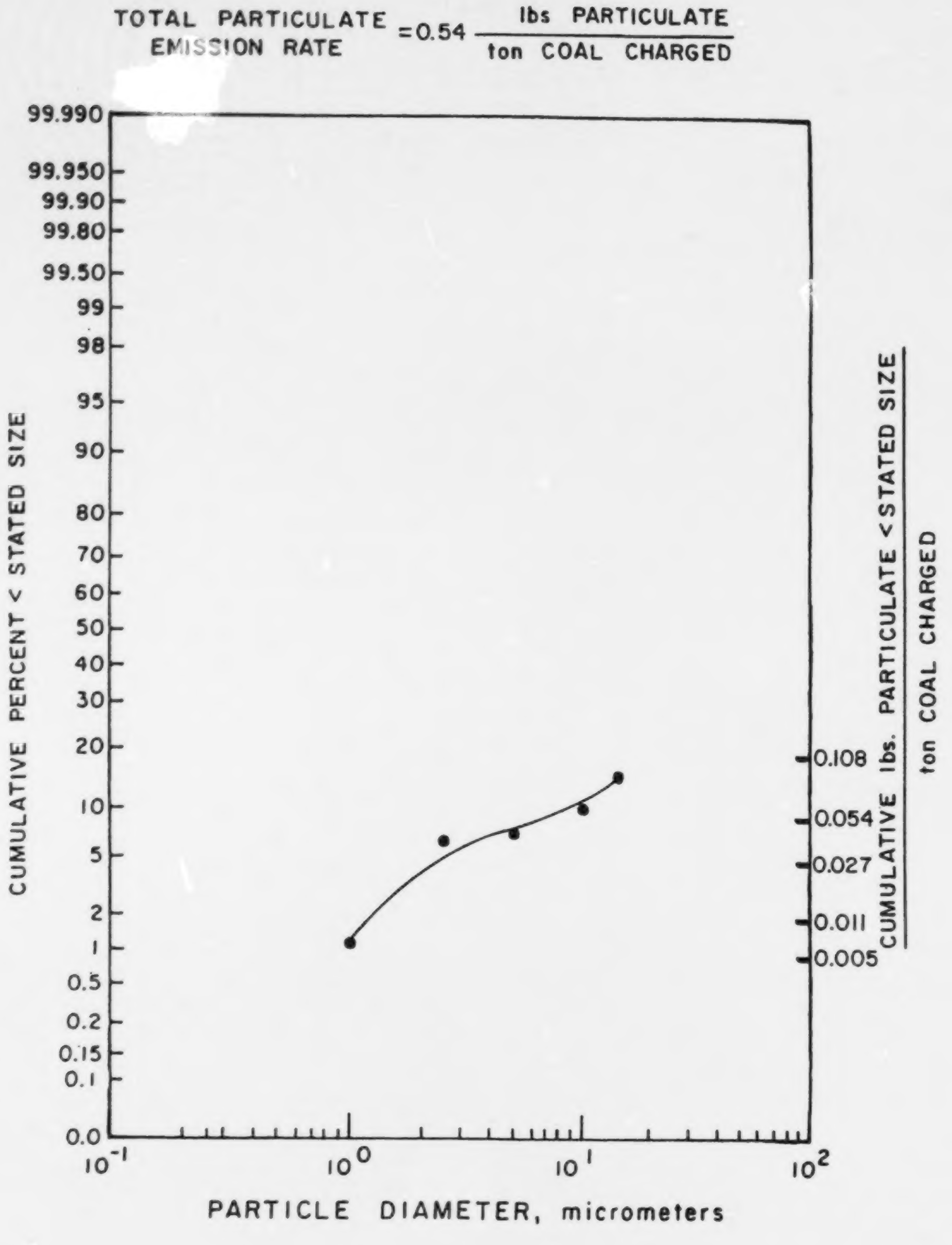
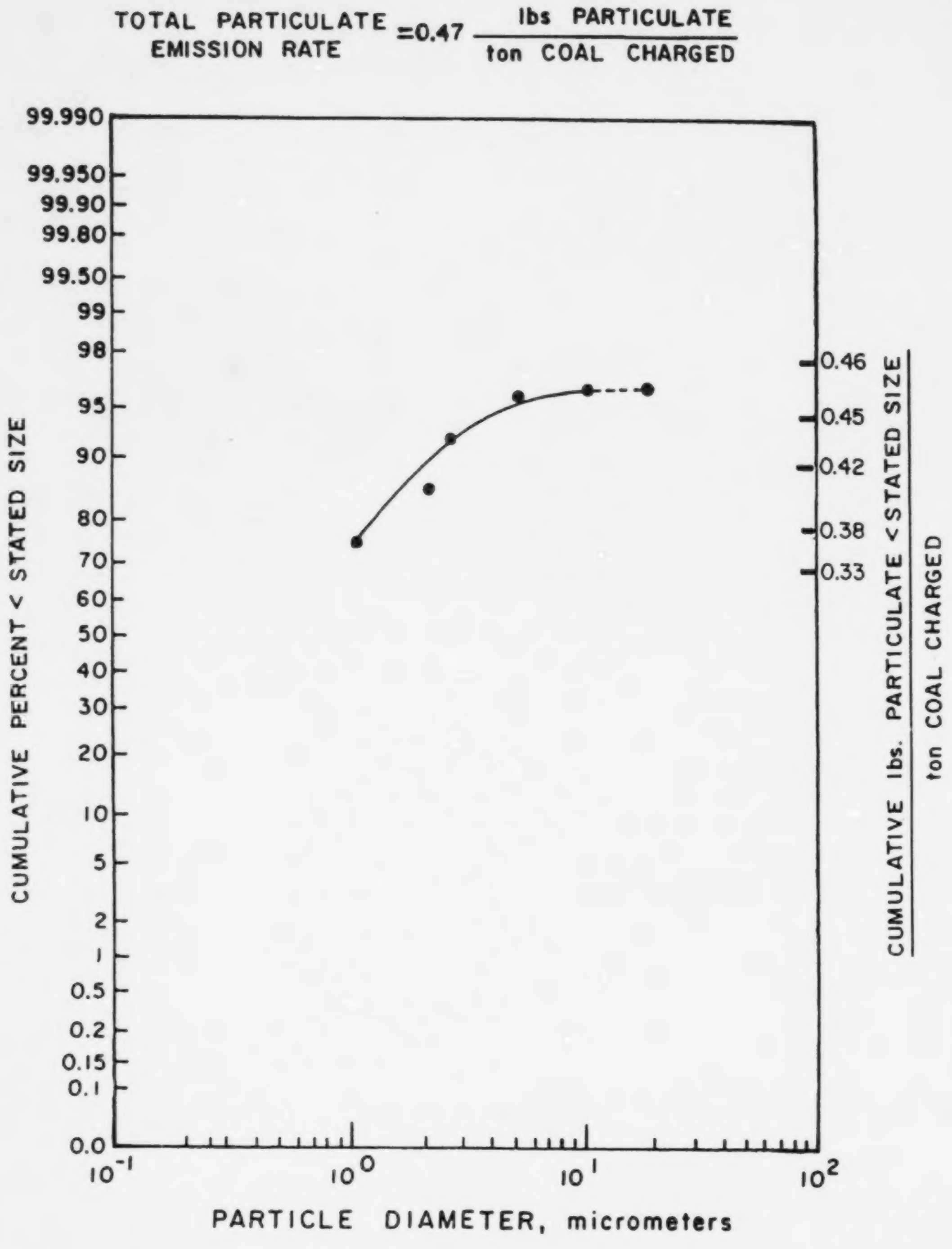


Figure 7.2-12. Quenching (controlled with baffles) clean water <1,500 mg/L TDS.



Note: Extrapolated to the 15 μm size, using engineering estimates.

Figure 7.2-13. Combustion stacks (uncontrolled) average of 3 sites.

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7.5 IRON AND STEEL PRODUCTION

7.5.1 Process Description[1-3]

The production of steel at an integrated iron and steel plant is accomplished using several interrelated processes. The major operations are: (1) coke production, (2) sinter production, (3) iron production, (4) iron preparation, (5) steel production, (6) semifinished product preparation, (7) finished product preparation, (8) heat and electricity supply, and (9) handling and transport of raw, intermediate and waste materials. The interrelation of these operations is depicted in a general flow diagram of the iron and steel industry in Figure 7.5-1. Coke production is discussed in detail in Section 7.2 of this publication, and more information on the handling and transport of materials is found in Chapter 11.

7.5.1.1 Sinter Production - The sintering process converts fine sized raw materials, including iron ore, coke breeze, limestone, mill scale, and flue dust, into an agglomerated product, sinter, of suitable size for charging into the blast furnace. The raw materials are sometimes mixed with water to provide a cohesive matrix, and then placed on a continuous, travelling grate called the sinter strand. A burner hood, at the beginning of the sinter strand ignites the coke in the mixture, after which the combustion is self supporting and it provides sufficient heat, 1300 to 1480°C (2400 to 2700°F), to cause surface melting and agglomeration of the mix. On the underside of the sinter strand is a series of windboxes that draw combusted air down through the material bed into a common duct leading to a gas cleaning device. The fused sinter is discharged at the end of the sinter strand, where it is crushed and screened. Undersize sinter is recycled to the mixing mill and back to the strand. The remaining sinter product is cooled in open air or in a circular cooler with water sprays or mechanical fans. The cooled sinter is crushed and screened for a final time, then the fines are recycled, and the product is sent to be charged to the blast furnaces. Generally, 2.5 tons of raw materials, including water and fuel, are required to produce one ton of product sinter.

7.5.1.2 Iron Production - Iron is produced in blast funaces by the reduction of iron bearing materials with a hot gas. The large, refractory lined furnace is charged through its top with iron as ore, pellets, and/or sinter; flux as limestone, dolomite and sinter; and coke for fuel. Iron oxides, coke and fluxes react with the blast air to form molten reduced iron, carbon monoxide and slag. The molten iron and slag collect in the hearth at the base of the furnace. The byproduct gas is collected through offtakes located at the top of the furnace and is recovered for use as fuel.

The production of one ton of iron requires 1.4 tons of ore or other iron bearing material; 0.5 to 0.65 tons of coke; 0.25 tons of limestone or dolomite; and 1.8 to 2 tons of air. Byproducts consist of 0.2 to 0.4 tons of slag, and 2.5 to 3.5 tons of blast furnace gas containing up to 100 lbs of dust.

The molten iron and slag are removed, or cast, from the furnace periodically. The casting process begins with drilling a hole, called the taphole, into the clay filled iron notch at the base of the hearth. During casting, molten iron flows into runners that lead to transport ladles. Slag also flows

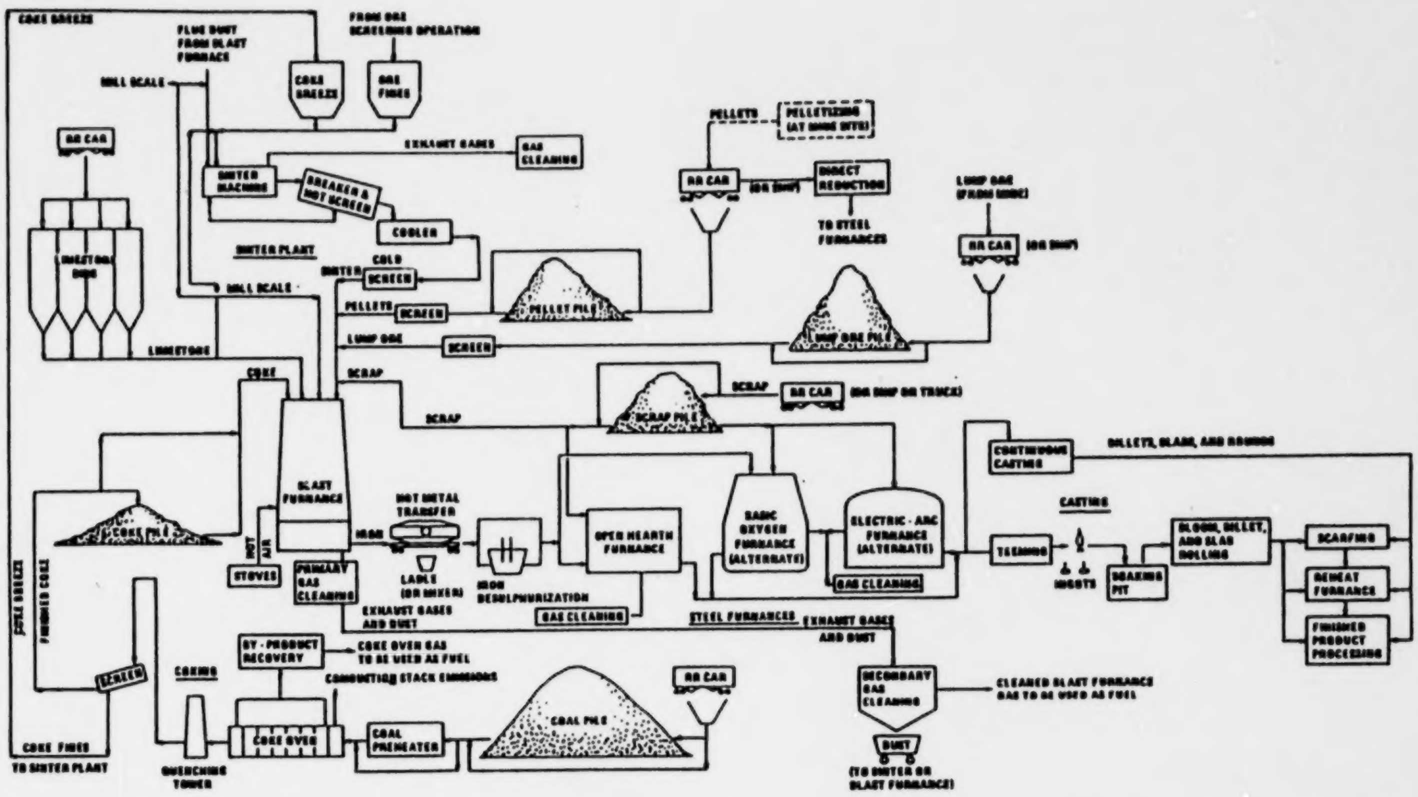

COKE BREEZE
FLUE DUST FROM BLAST FURNACE
FROM ORE SCREENING OPERATION
MILL SCALE
COKE BREEZE
ORE FINES
RR CAR
EXHAUST GASES
GAS CLEANING
SINTER MACHINE
BREAKER & HOT SCREEN
COOLER
LIMESTONE BINS
SINTER PLANT
COLD
SINTER
SCREEN
MILL SCALE
PELLETS
SCREEN
PELLET PILE
LIMESTONE
LUMP ORE
SCREEN
PELLETS
PELLETIZING (AT MINE SITE)
RR CAR
(OR SHIP)
DIRECT REDUCTION
TO STEEL FURNACES
LUMP ORE (FROM MINE)
RR CAR
(OR SHIP)
LUMP ORE PILE
COKE
SCRAP
SCRAP
SCRAP
RR CAR
(OR SHIP OR TRUCK)
SCRAP PILE
BLAST FURNACE
COKE PILE
HOT AIR
STOVES
PRIMARY GAS CLEANING
IRON
HOT METAL TRANSFER
LADLE (OR MIXER)
IRON DESULPHURIZATION
OPEN HEARTH FURNACE
BASIC OXYGEN FURNACE (ALTERNATE)
ELECTRIC - ARC FURNACE (ALTERNATE)
GAS CLEANING
GAS CLEANING
STEEL FURNACES
EXHAUST GASES AND DUST
EXHAUST GASES AND DUST
CONTINUOUS CASTING
BILLETS, SLABS, AND ROUNDS
CASTING
TEEMING
INGOTS
SOAKING PIT
BLOOM, BILLET, AND SLAB ROLLING
SCARFING
REHEAT FURNACE
FINISHED PRODUCT PROCESSING
COKE BREEZE
FINISHED COKE
SCREEN
COKING
BY - PRODUCT RECOVERY
COKE OVEN GAS TO BE USED AS FUEL
COMBUSTION STACK EMISSIONS
COKE FINES TO SINTER PLANT
QUENCHING TOWER
COKE OVEN
COAL PREHEATER
COAL PILE
RR CAR
SECONDARY GAS CLEANING
CLEANED BLAST FURNACE GAS TO BE USED AS FUEL
DUST
(TO SINTER OR BLAST FURNACE)

Figure 7.5-1. General flow diagram for the iron and steel industry.

into the clay filled iron notch at the base of the hearth. During casting, molten iron flows into runners that lead to transport ladles. Slag also flows from the furnace, and is directed through separate runners to a slag pit adjacent to the casthouse, or into slag pots for transport to a remote slag pit. At the conclusion of the cast, the taphole is replugged with clay. The area around the base of the furnace, including all iron and slag runners, is enclosed by a casthouse. The blast furnace byproduct gas, which is collected from the furnace top, contains carbon monoxide and particulate. Because of its high carbon monoxide content, this blast furnace gas has a low heating value, about 2790 to 3350 joules per liter (75 to 90 BTU/ft^3) and is used as a fuel within the steel plant. Before it can be efficiently oxidized, however, the gas must be cleaned of particulate. Initially, the gases pass through a settling chamber or dry cyclone to remove about 60 percent of the particulate. Next, the gases undergo a one or two stage cleaning operation. The primary cleaner is normally a wet scrubber, which removes about 90 percent of the remaining particulate. The secondary cleaner is a high energy wet scrubber (usually a venturi) or an electrostatic precipitator, either of which can remove up to 90 percent of the particulate that eludes the primary cleaner. Together these control devices provide a clean fuel of less than 0.05 grams per cubic meter (0.02 gr/ft^3). A portion of this gas is fired in the blast furnace stoves to preheat the blast air, and the rest is used in other plant operations.

7.5.1.3 Iron Preparation Hot Metal Desulfurization - Sulfur in the molten iron is sometimes reduced before charging into the steelmaking furnace by adding reagents. The reaction forms a floating slag which can be skimmed off. Desulfurization may be performed in the hot metal transfer (torpedo) car at a location between the blast furnace and basic oxygen furnace (BOF), or it may be done in the hot metal transfer (torpedo) ladle at a station inside the BOF shop.

The most common reagents are powdered calcium carbide (CaC_2) and calcium carbonate ($CaCO_3$) or salt coated magnesium granules. Powdered reagents are injected into the metal through a lance with high pressure nitrogen. The process duration varies with the injection rate, hot metal chemistry, and desired final sulfur content, and is in the range of 5 to 30 minutes.

7.5.1.4 Steelmaking Process - Basic Oxygen Furnaces - In the basic oxygen process (BOP), molten iron from a blast furance and iron scrap are refined in a furnace by lancing (or injecting) high purity oxygen. The input material is typically 70 percent molten metal and 30 percent scrap metal. The oxygen reacts with carbon and other impurities to remove them from the metal. The reactions are exothermic, i. e., no external heat source is necessary to melt the scrap and to raise the temperature of the metal to the desired range for tapping. The large quantities of carbon monoxide (CO) produced by the reactions in the BOF can be controlled by combustion at the mouth of the furnace and then vented to gas cleaning devices, as with open hoods, or combustion can be suppressed at the furnace mouth, as with closed hoods. BOP steelmaking is conducted in large (up to 400 ton capacity) refractory lined pear shaped furnaces. There are two major variations of the process. Conventional BOFs have oxygen blown into the top of the furnace through a water cooled lance. In the newer, Quelle Basic Oxygen process (Q-BOP), oxygen is injected through tuyeres located in the bottom of the furnace. A typical BOF cycle consists of the scrap charge, hot metal charge, oxygen blow (refining) period, testing for temperature and chemical composition of the steel, alloy additions and reblows (if necessary), tapping, and slagging. The full furnace cycle typically ranges from 25 to 45 minutes.

7.5.1.5 Steelmaking Process - Electric Arc Furnace - Electric arc furnaces (EAF) are used to produce carbon and alloy steels. The input material to an EAF is typically 100 percent scrap. Cylindrical, refractory lined EAFs are equipped with carbon electrodes to be raised or lowered through the furnace roof. With electrodes retracted, the furnace roof can be rotated aside to permit the charge of scrap steel by overhead crane. Alloying agents and fluxing materials usually are added through the doors on the side of the furnace. Electric current of the opposite polarity electrodes generates heat between the electrodes and through the scrap. After melting and refining periods, the slag and steel are poured from the furnace by tilting.

The production of steel in an EAF is a batch process. Cycles, or "heats", range from about 1 1/2 to 5 hours to produce carbon steel and from 5 to 10 hours or more to produce alloy steel. Scrap steel is charged to begin a cycle, and alloying agents and slag materials are added for refining. Stages of each cycle normally are charging and melting operations, refining (which usually includes oxygen blowing), and tapping.

7.5.1.6 Steelmaking Process-Open Hearth Furnaces - The open hearth furnace (OHF) is a shallow, refractory-lined basin in which scrap and molten iron are melted and refined into steel. Scrap is charged to the furnace through doors in the furnace front. Hot metal from the blast furnace is added by pouring from a ladle through a trough positioned in the door. The mixture of scrap and hot metal can vary from all scrap to all hot metal, but a half and half mixture is most common. Melting heat is provided by gas burners above and at the side of the furnace. Refining is accomplished by the oxidation of carbon in the metal and the formation of a limestone slag to remove impurities. Most furnaces are equipped with oxygen lances to speed up melting and refining. The steel product is tapped by opening a hole in the base of the furnace with an explosive charge. The open hearth steelmaking process with oxygen lancing normally requires from 4 to 10 hours for each heat.

7.5.1.7 Semifinished Product Preparation - After the steel has been tapped, the molten metal is teemed (poured) into ingots which are later heated and formed into other shapes, such as blooms, billets, or slabs. The molten steel may bypass this entire process and go directly to a continuous casting operation. Whatever the production technique, the blooms, billets, or slabs undergo a surface preparation step, scarfing, which removes surface defects before shaping or rolling. Scarfing can be performed by a machine applying jets of oxygen to the surface of hot semifinished steel, or by hand (with torches) on cold or slightly heated semifinished steel.

7.5.2 Emissions And Controls

7.5.2.1 Sinter - Emissions from sinter plants are generated from raw material handling, windbox exhaust, discharge end (associated sinter crushers and hot screens), cooler and cold screen. The windbox exhaust is the primary source of particulate emissions, mainly iron oxides, sulfur oxides, carbonaceous compounds, aliphatic hydrocarbons, and chlorides. At the discharge end, emissions are mainly iron and calcium oxides. Sinter strand windbox emissions commonly are controlled by cyclone cleaners followed by a dry or wet ESP, high pressure drop wet scrubber, or baghouse. Crusher and hot screen emissions, usually controlled by hooding and a baghouse or scrubber, are the next largest emissions source. Emissions are also generated from other material handling operations. At some sinter plants, these emissions are captured and vented to a baghouse.

7.5.2.2 Blast Furnace - The primary source of blast furnace emissions is the casting operation. Particulate emissions are generated when the molten iron and slag contact air above their surface. Casting emissions also are generated by drilling and plugging the taphole. The occasional use of an oxygen lance to open a clogged taphole can cause heavy emissions. During the casting operation, iron oxides, magnesium oxide and carbonaceous compounds are generated as particulate. Casting emissions at existing blast furnaces are controlled by evacuation through retrofitted capture hoods to a gas cleaner, or by suppression techniques. Emissions controlled by hoods and an evacuation system are usually vented to a baghouse. The basic concept of suppression techniques is to prevent the formation of pollutants by excluding ambient air contact with the molten surfaces. New furnaces have been constructed with evacuated runner cover systems and local hooding ducted to a baghouse.

Another potential source of emissions is the blast furnace top. Minor emissions may occur during charging from imperfect bell seals in the double bell system. Occasionally, a cavity may form in the blast fuernace charge, causing a collapse of part of the burden (charge) above it. The resulting pressure surge in the furnace opens a relief valve to the atmosphere to prevent damage to the furnace by the high pressure created and is referred to as a "slip".

7.5.2.3 Hot Metal Desulfurization - Emissions during the hot metal desulfurization process are created by both the reaction of the reagents injected into the metal and the turbulence during injection. The pollutants emitted are mostly iron oxides, calcium oxides and oxides of the compound injected. The sulfur reacts with the reagents and is skimmed off as slag. The emissions generated from desulfurization may be collected by a hood positioned over the ladle and vented to a baghouse.

7.5.2.4 Steelmaking - The most significant emissions from the BOF process occur during the oxygen blow period. The predominant compounds emitted are iron oxides, although heavy metals and fluorides are usually present. Charging emissions will vary with the quality and quantity of scrap metal charged to the furnace and with the pour rate. Tapping emissions include iron oxides, sulfur oxides, and other metallic oxides, depending on the grade of scrap used. Hot metal transfer emissions are mostly iron oxides.

BOFs are equipped with a primary hood capture system located directly over the open mouth of the furnaces to control emissions during oxygen blow periods. Two types of capture systems are used to collect exhaust gas as it leaves the furnace mouth: closed hood (also known as an off gas, or O. G., system) or open, combustion type hood. A closed hood fits snugly against the furnace mouth, ducting all particulate and carbon monoxide to a wet scrubber gas cleaner. Carbon monoxide is flared at the scrubber outlet stack. The open hood design allows dilution air to be drawn into the hood, thus combusting the carbon monoxide in the hood system. Charging and tapping emissions are controlled by a variety of evacuation systems and operating practices. Charging hoods, tapside enclosures, and full furnace enclosures are used in the industry to capture these emissions and send them to either the primary hood gas cleaner or a second gas cleaner.

7.5.2.5 Steelmaking - Electric Arc Furnace - The operations which generate emissions during the electric arc furnace steelmaking process are melting and refining, charging scrap, tapping steel, and dumping slag. Iron oxide is the predominant constituent of the particulate emitted during melting. During refining, the primary particulate compound emitted is calcium oxide from the slag. Emissions from charging scrap are difficult to quantify, because they depend on the grade of scrap utilized. Scrap emissions usually contain iron and other metallic oxides from alloys in the scrap metal. Iron oxides and oxides from the fluxes are the primary constituents of the slag emissions. During tapping, iron oxide is the major particulate compound emitted.

Emission control techniques involve an emission capture system and a gas cleaning system. Five emission capture systems used in the industry are fourth hold (direct shell) evacuation, side draft hood, combination hood, canopy hood, and furnace enclosures. Direct shell evacuation consists of ductwork attached to a separate or fourth hole in the furnace roof which draws emissions to a gas cleaner. The fourth hole system works only when the furnace is upright with the roof in place. Side draft hoods collect furnace off gases from around the electrode holes and the work doors after the gases leave the furnace. The combination hood incorporates elements from the side draft and fourth hole ventilation systems. Emissions are collected both from the fourth hole and around the electrodes. An air gap in the ducting introduces secondary air for combustion of CO in the exhaust gas. The combination hood requires careful regulation of furnace interval pressure. The canopy hood is the least efficient of the four ventilation systems, but it does capture emissions during charging and tapping. Many new electric arc furnaces incorporate the canopy hood with one of the other three systems. The full furnace enclosure completely surrounds the furnace and evacuates furnace emissions through hooding in the top of the enclosure.

7.5.2.6 Steelmaking - Open Hearth Furnace - Particulate emissions from an open hearth furnace vary considerably during the process. The use of oxygen lancing increases emissions of dust and fume. During the melting and refining cycle, exhaust gas drawn from the furnace passes through a slag pocket and a regenerative checker chamber, where some of the particulate settles out. The emissions, mostly iron oxides, are then ducted to either an ESP or a wet scrubber. Other furnace related process operations which produce fugitive emissions inside the shop include transfer and charging of hot metal, charging of scrap, tapping steel and slag dumping. These emissions are usually uncontrolled.

7.5.2.7 Semifinished Product Preparation - During this activity, emissions are produced when molten steel is poured (teemed) into ingot molds, and when semifinished steel is machine or manually scarfed to remove surface defects. Pollutants emitted are iron and other oxides (FeO, Fe_2O_3, SiO_2, CaO, MgO).

Teeming emissions are rarely controlled. Machine scarfing operations generally use as ESP or water spray chamber for control. Most hand scarfing operations are uncontrolled.

7.5.2.8 Miscellaneous Combustion - Every iron and steel plant operation requires energy in the form of heat or electricity. Combustion sources that produce emissions on plant property are blast furnace stoves, boilers, soaking pits, and reheat furnaces. These facilities burn combinations of coal, No. 2 fuel oil, natural gas, coke oven gas, and blast furnace gas. In blast furnace stoves, clean gas from the blast furnace is burned to heat the refractory checker work, and in turn, to heat the blast air. In soaking pits, ingots are heated until the temperature distribution over the cross section of the ingots is acceptable and the surface temperature is uniform for further rolling into semifinished products (blooms, billets and slabs). In slab furnaces, a slab is heated before being rolled into finished products (plates, sheets or strips). Emissions from the combustion of natural gas, fuel oil or coal in the soaking pits or slab furnaces are estimated to be the same as those for boilers. (See Chapter 1 of this document.) Emission factor data for blast furnace gas and coke oven gas are not available and must be estimatexW There are three facts available for making the estimation. First, the gas exiting the blast furnace passes through primary and secondary cleaners and can be cleaned to less than 0.05 grams per cubic meter (0.02 gr/ft^3). Second, nearly one third of the coke oven gas is methane. Third, there are no blast furnace gas constituents that generate particulate when burned. The combustible constituent of blast furnace gas is CO, which burns clean. Based on facts one and three, the emission factor for combustion of blast furnace gas is equal to the particulate loading of that fuel, 0.05 grams per cubic meter (2.9 lb/10^6 ft^3) having an average heat value of 83 BTU/ft^3.

Emissions for combustion of coke oven gas can be estimated in the same fashion. Assume that cleaned coke oven gas has as much particulate as cleaned blast furnace gas. Since one third of the coke oven gas is methane, the main component of natural gas, it is assumed that the combustion of this methane in coke oven gas generates 0.06 grams per cubic meter (3.3 lb/10^6 ft^3) of particulate. Thus, the emission factor for the combustion of coke oven gas is the sum of the particulate loading and that generated by the methane combustion, or 0.1 grams per cubic meter (6.2 lb/10^6 ft^3) having an average heat value of 516 BTU/ft^3.

The particulate emission factors for processes in Table 7.5-1 are the result of an extensive investigation by EPA and the American Iron and Steel Institute.[3] Particle size distributions for controlled and uncontrolled emissions from specific iron and steel industry processes have been calculated and summarized from the best available data.[1] Size distributions have been used with particulate emission factors to calculate size specific factors for the sources listed in Table 7.5-1 for which data are available. Table 7.5-2 presents these size specific particulate emission factors. Particle size distributions are presented in Figures 7.5-2 to 7.5-4. Carbon monoxide emission factors are in Table 7.5-3.[6]

TABLE 7.5-1. PARTICULATE EMISSION FACTORS FOR IRON AND STEEL MILLS[a]

Source	Units	Emission Factor	Emission Factor Rating	Particle Size Data
Sintering				
Windbox	kg/Mg (lb/ton) finished sinter			
Uncontrolled				
Leaving grate		5.56 (11.1)	B	Yes
After coarse particulate removal		4.35 (8.7)	A	
Controlled by dry ESP		0.8 (1.6)	B	
Controlled by wet ESP		0.085 (0.17)	B	Yes
Controlled by venturi scrubber		0.235 (0.47)	B	Yes
Controlled by cyclone		0.5 (1.0)	B	Yes
Sinter discharge (breaker and hot screens)	kg/Mg (lb/ton) finished sinter			
Uncontrolled		3.4 (6.8)	B	
Controlled by baghouse		0.05 (0.1)	B	Yes
Controlled by venturi scrubber		0.295 (0.59)	A	
Windbox and discharge	kg/Mg (lb/ton) finished sinter			
Controlled by baghouse		0.15 (0.3)	A	
Blast furnace				
Slip	kg/Mg (lb/ton) slip	39.5 (87.0)	D	
Uncontrolled casthouse Roof Monitor[b]	kg/Mg (lb/ton) hot metal	0.3 (0.6)	B	Yes
Furnace with local evacuation[c]		0.65 (1.3)	B	Yes
Taphole and trough only (not runners)		0.15 (0.3)	B	
Hot metal desulfurization				
Uncontrolled[d]	kg/Mg (lb/ton) hot metal	0.55 (1.09)	D	Yes
Controlled by baghouse		0.0045 (0.009)	D	Yes
Basic oxygen furnace (BOF)				
Top blown furnace melting and refining	kg/Mg (lb/ton) steel			
Uncontrolled		14.25 (28.5)	B	
Controlled by open hood vented to:				
ESP		0.065 (0.13)	A	
Scrubber		0.045 (0.09)	B	
Controlled by closed hood vented to:				
Scrubber		0.0034 (0.0068)	A	Yes

TABLE 7.5-1 (cont.). PARTICULATE EMISSION FACTORS FOR IRON AND STEEL MILLS[a]

Source	Units	Emission Factor	Emission Factor Rating	Particle Size Data
BOF Charging	kg/Mg (lb/ton) hot metal			
At source		0.3 (0.6)	D	Yes
At building monitor		0.071 (0.142)	B	
Controlled by baghouse		0.0003 (0.0006)	B	Yes
BOF Tapping	kg/Mg (lb/ton) steel			
At source		0.46 (0.92)	D	Yes
At building monitor		0.145 (0.29)	B	
Controlled by baghouse		0.0013 (0.0026)	B	Yes
Hot metal transfer	kg/Mg (lb/ton) hot metal			
At source		0.095 (0.19)	A	
At building monitor		0.028 (0.056)	B	
BOF monitor (all sources)	kg/Mg (lb/ton) steel	0.25 (0.5)	B	
Q-BOP melting and refining	kg/Mg (lb/ton) steel			
Controlled by scrubber		0.028 (0.056)	B	Yes
Electric arc furnace				
Melting and refining	kg/Mg (lb/ton) steel			
Uncontrolled carbon steel		19.0 (38.0)	C	Yes
Charging, tapping and slagging	kg/Mg (lb/ton) steel			
Uncontrolled emissions escaping monitor		0.7 (1.4)	C	
Melting, refining, charging, tapping and slagging	kg/Mg (lb/ton) steel			
Uncontrolled				
Alloy steel		5.65 (11.3)	A	
Carbon steel		25.0 (50.0)	C	
Controlled by:[e]				
Building evacuation to baghouse for alloy steel		0.15 (0.3)	A	
Direct shell evacuation (plus charging hood) vented to common baghouse for carbon steel		0.0215 (0.043)	E	Yes

TABLE 7.5-1 (Cont.). PARTICULATE EMISSION FACTORS FOR IRON AND STEEL MILLS

Source	Units	Emission Factor	Emission Factor Rating	Particle Size Data
Open hearth furnace				
Melting and refining	kg/Mg (lb/ton) steel			
Uncontrolled		10.55 (21.1)	D	Yes
Controlled by ESP		0.14 (0.28)	D	Yes
Roof monitor		0.084 (0.168)	C	
Teeming				
Leaded steel	kg/Mg (lb/ton) steel			
Uncontrolled (measured at source)		0.405 (0.81)	A	
Controlled by side draft hood vented to baghouse		0.0019 (0.0038)	A	
Unleaded steel				
Uncontrolled (measured at source)		0.035 (0.07)	A	
Controlled by side draft hood vented to baghouse		0.0008 (0.0016)	A	
Machine scarfing				
Uncontrolled	kg/Mg (lb/ton) metal through scarfer	0.05 (0.1)	B	
Controlled by ESP		0.0115 (0.023)	A	
Miscellaneous combustion sources[f]		f f		
Boiler, soaking pit and slab reheat	$kg/10^9$ J $(lb/10^6$ Btu)			
Blast furnace gas[g]		0.015 (0.035)	D	
Coke oven gas[g]		0.0052 (0.012)	D	

[a] Reference 3, except as noted.

[b] Typical of older furnaces with no controls, or for canopy hoods or total casthouse evacuation.

[c] Typical of large, new furnaces with local hoods and covered evaucated runners. Emissions are higher than without capture systems because they are not diluted by outside environment.

[d] Emission factor of 0.55 kg/Mg (1.09 lb/ton) represents one torpedo car; 1.26 kg/Mg (2.53 lb/ton) for two torpedo cars, and 1.37 kg/Mg (2.74 lb/ton) for three torpedo cars.

[e] Building evacuation collects all process emissions, and direct shell evacuation collects only melting and refining emissions.

[f] For various fuels, use the emission factors in Chapter 1 of this document. The emission factor rating, for these fuels in boilers is A, and in soaking pits and slab reheat furnaces is D.

[g] Based on methane content and cleaned particulate loading.

TABLE 7.5-2. SIZE SPECIFIC EMISSION FACTORS

Source	Emission Factor Rating	Particle Size μm[a]	Cumulative Mass % ≤ Stated size	Cumulative mass emission factor kg/Mg (lb/ton)
Sintering				
Windbox				
Uncontrolled				
Leaving grate	D	0.5	4[b]	0.22 (0.44)
		1.0	4	0.22 (0.44)
		2.5	5	0.28 (0.56)
		5.0	9	0.50 (1.00)
		10	15	0.83 (1.67)
		15	20[c]	1.11 (2.22)
		d	100	5.56 (11.1)
Controlled by wet ESP	C	0.5	18[b]	0.015 (0.03)
		1.0	25	0.021 (0.04)
		2.5	33	0.028 (0.06)
		5.0	48	0.041 (0.08)
		10	59[b]	0.050 (0.10)
		15	69	0.059 (0.12)
		d	100	0.085 (0.17)
Controlled by venturi scrubber	C	0.5	55	0.129 (0.26)
		1.0	75	0.176 (0.35)
		2.5	89	0.209 (0.42)
		5.0	93	0.219 (0.44)
		10	96	0.226 (0.45)
		15	98	0.230 (0.46)
		d	100	0.235 (0.47)
Controlled by cyclone[e]	C	0.5	25[c]	0.13 (0.25)
		1.0	37[b]	0.19 (0.37)
		2.5	52	0.26 (0.52)
		5.0	64	0.32 (0.64)
		10	74	0.37 (0.74)
		15	80	0.40 (0.80)
		d	100	0.5 (1.0)
Controlled by baghouse	C	0.5	3.0	0.005 (0.009)
		1.0	9.0	0.014 (0.027)
		2.5	27.0	0.041 (0.081)
		5.0	47.0	0.071 (0.141)
		10.0	69.0	0.104 (0.207)
		15.0	79.0	0.119 (0.237)
		d	100.0	0.15 (0.3)

TABLE 7.5.2 (cont.) SIZE SPECIFIC EMISSION FACTORS

Source	Emission Factor Rating	Particle Size µm[a]	Cumulative Mass % ≤ Stated size	Cumulative mass emission factor kg/Mg (lb/ton)
Sinter discharge (breaker and hot screens) controlled by baghouse	C	0.5	2[b]	0.001 (0.002)
		1.0	4	0.002 (0.004)
		2.5	11	0.006 (0.011)
		5.0	20	0.010 (0.020)
		10	32[b]	0.016 (0.032)
		15	42[b]	0.021 (0.042)
		d	100	0.05 (0.1)
Blast furnace Uncontrolled cast-house emissions Roof monitor[f]	C	0.5	4	0.01 (0.02)
		1.0	15	0.05 (0.09)
		2.5	23	0.07 (0.14)
		5.0	35	0.11 (0.21)
		10	51	0.15 (0.31)
		15	61	0.18 (0.37)
		d	100	0.3 (0.6)
Furnace with local evacuation[g]	C	0.5	7[c]	0.04 (0.09)
		1.0	9	0.06 (0.12)
		2.5	15	0.10 (0.20)
		5.0	20	0.13 (0.26)
		10	24	0.16 (0.31)
		15	26	0.17 (0.34)
		d	100	0.65 (1.3)
Hot metal desulfurization[h] Uncontrolled	E	0.5	j	
		1.0	2[c]	0.01 (0.02)
		2.5	11	0.06 (0.12)
		5.0	19	0.10 (0.22)
		10	19	0.10 (0.22)
		15	21	0.12 (0.23)
		d	100	0.55 (1.09)
Hot metal desulfurization[h] Controlled baghouse	D	0.5	8	0.0004 (0.0007)
		1.0	18	0.0009 (0.0016)
		2.5	42	0.0019 (0.0038)
		5.0	62	0.0028 (0.0056)
		10	74	0.0033 (0.0067)
		15	78	0.0035 (0.0070)
		d	100	0.0045 (0.009)

TABLE 7.5-2 (cont.) SIZE SPECIFIC EMISSION FACTORS

Source	Emission Factor Rating	Particle Size µm[a]	Cumulative Mass % ≤ Stated size	Cumulative mass emission factor kg/Mg (lb/ton)
Basic oxygen furnace				
Top blown furnace melting and refining controlled by closed hood and vented to scrubber	C	0.5	34	0.0012 (0.0023)
		1.0	55	0.0019 (0.0037)
		2.5	65	0.0022 (0.0044)
		5.0	66	0.0022 (0.0045)
		10	67	0.0023 (0.0046)
		15	72[c]	0.0024 (0.0049)
		d	100	0.0034 (0.0068)
BOF Charging				
At source[k]	E	0.5	8[c]	0.02 (0.05)
		1.0	12	0.04 (0.07)
		2.5	22	0.07 (0.13)
		5.0	35	0.10 (0.21)
		10	46	0.14 (0.28)
		15	56	0.17 (0.34)
		d	100	0.3 (0.6)
Controlled by baghouse	D	0.5	3	9.0×10^{-6} 1.8×10^{-5}
		1.0	10	3.0×10^{-5} 6.0×10^{-5}
		2.5	22	6.6×10^{-5} (0.0001)
		5.0	31	9.3×10^{-5} (0.0002)
		10	45	0.0001 (0.0003)
		15	60	0.0002 (0.0004)
		d	100	0.0003 (0.0006)
BOF Tapping				
At source[k]	E	0.5	j	j j
		1.0	11	0.05 (0.10)
		2.5	37	0.17 (0.34)
		5.0	43	0.20 (0.40)
		10	45	0.21 (0.41)
		15	50	0.23 (0.46)
		d	100	0.46 (0.92)

TABLE 7.5-2 (cont.) SIZE SPECIFIC EMISSION FACTORS

Source	Emission Factor Rating	Particle Size m[a]	Cumulative Mass % < Stated size	Cumulative mass emission factor kg/Mg (lb/ton)
BOF Tapping Controlled by baghouse	D	0.5	4	$5.2x10^{-5}$ (0.0001)
		1.0	7	0.0001 (0.0002)
		2.5	16	0.0002 (0.0004)
		5.0	22	0.0003 (0.0006)
		10	30	0.0004 (0.0008)
		15	40	0.0005 (0.0010)
		d	100	0.0013 (0.0026)
Q-BOP melting and refining controlled by scrubber	D	0.5	45	0.013 (0.025)
		1.0	52	0.015 (0.029)
		2.5	56	0.016 (0.031)
		5.0	58	0.016 (0.032)
		10	68	0.019 (0.038)
		15	85[c]	0.024 (0.048)
		d	100	0.028 (0.056)
Electric arc furnace melting and refining carbon steel uncontrolled[m]	D	0.5	8	1.52 (3.04)
		1.0	23	4.37 (8.74)
		2.5	43	8.17 (16.34)
		5.0	53	10.07 (20.14)
		10	58	11.02 (22.04)
		15	61	11.59 (23.18)
		d	100	19.0 (38.0)
Electric arc furnace Melting, refining, charging, tapping, slagging Controlled by direct shell evacuation (plus charging hood) vented to common baghouse for carbon steel[n]	E	0.5	74[b]	0.0159 (0.0318)
		1.0	74	0.0159 (0.0318)
		2.5	74	0.0159 (0.0318)
		5.0	74	0.0159 (0.0318)
		10	76	0.0163 (0.0327)
		15	80	0.0172 (0.0344)
		d	100	0.0215 (0.043)

TABLE 7.5-2 (cont.) SIZE SPECIFIC EMISSION FACTORS

Source	Emission Factor Rating	Particle Size μm[a]	Cumulative Mass, % ≤ Stated size	Cumulative mass emission factor kg/Mg (lb/ton)
Open hearth furnace Melting and refining Uncontrolled	E	0.5	1[b]	0.11 (0.21)
		1.0	21	2.22 (4.43)
		2.5	60	6.33 (12.66)
		5.0	79	8.33 (16.67)
		10	83	8.76 (17.51)
		15	85[c]	8.97 (17.94)
		d	100	10.55 (21.1)
Open Hearth Furnaces Controlled by ESPP	E	0.5	10[b]	0.01 (0.02)
		1.0	21	0.03 (0.06)
		2.5	39	0.05 (0.10)
		5.0	47	0.07 (0.13)
		10	53[b]	0.07 (0.15)
		15	56[b]	0.08 (0.16)
		d	100	0.14 (0.28)

[a] Particle aerodynamic diameter micrometers (μm) as defined by Task Group on Lung Dynamics. (Particle density = 1 gr/cm^3).

[b] Interpolated data used to develop size distribution.

[c] Extrapolated, using engineering estimates.

[d] Total particulate based on Method 5 total catch. See Table 7.5-1.

[e] Average of various cyclone efficiencies.

[f] Total casthouse evacuation control system.

[g] Evacuation runner covers and local hood over taphole, typical of new state of the art blast furnace technology.

[h] Torpedo ladle desulfurization with CaC_2 and $CaCO_3$.

[j] Unable to extrapolate because of insufficient data and/or curve exceeding limits.

[k] Doghouse type furnace enclosure using front and back sliding doors, totally enclosing the furnace, with emissions vented to hoods.

[m] Full cycle emissions captured by canopy and side draft hoods.

[n] Information on control system not available.

[p] May not be representative. Test outlet size distribution was larger than inlet and may indicate reentrainment problem.

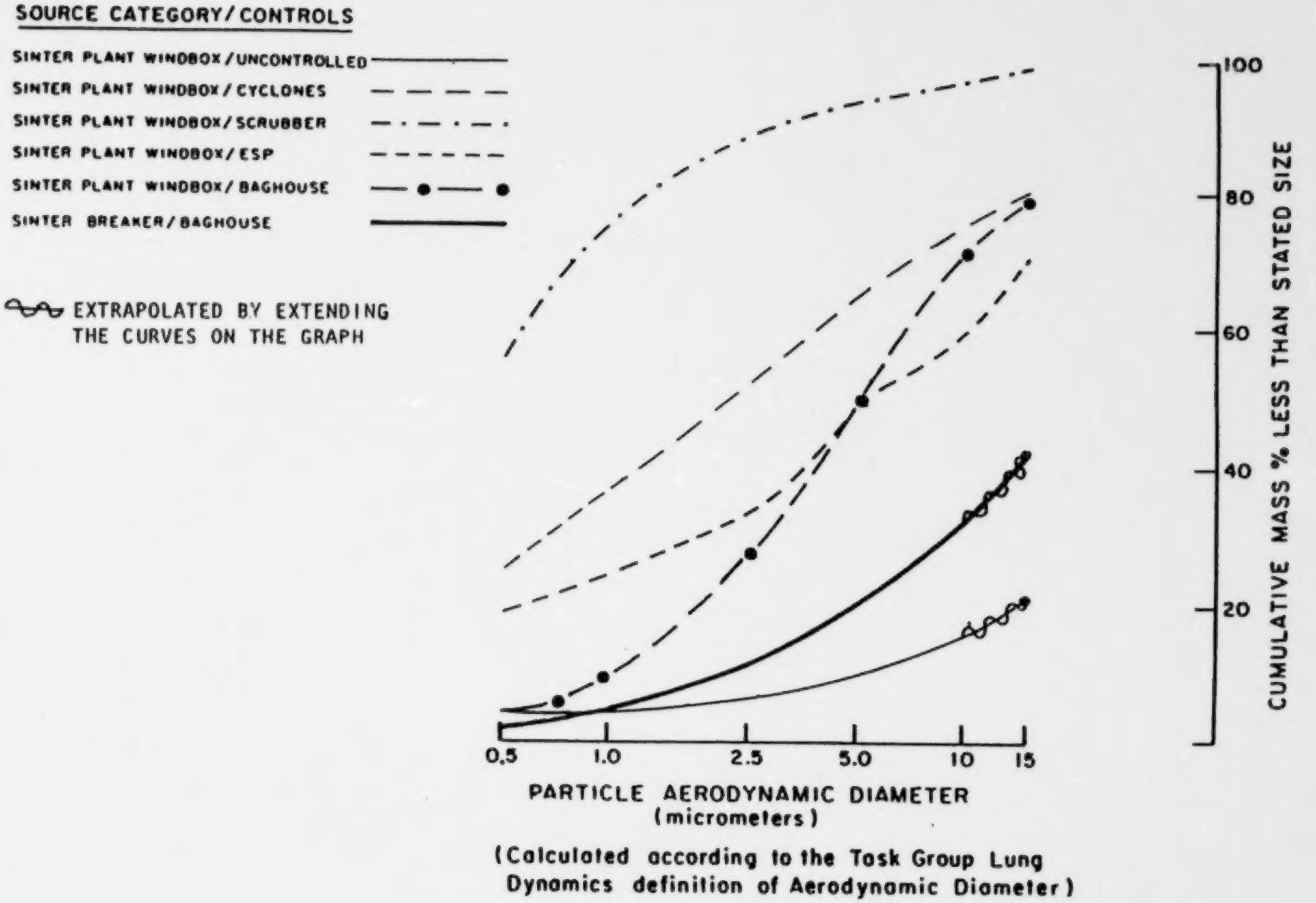
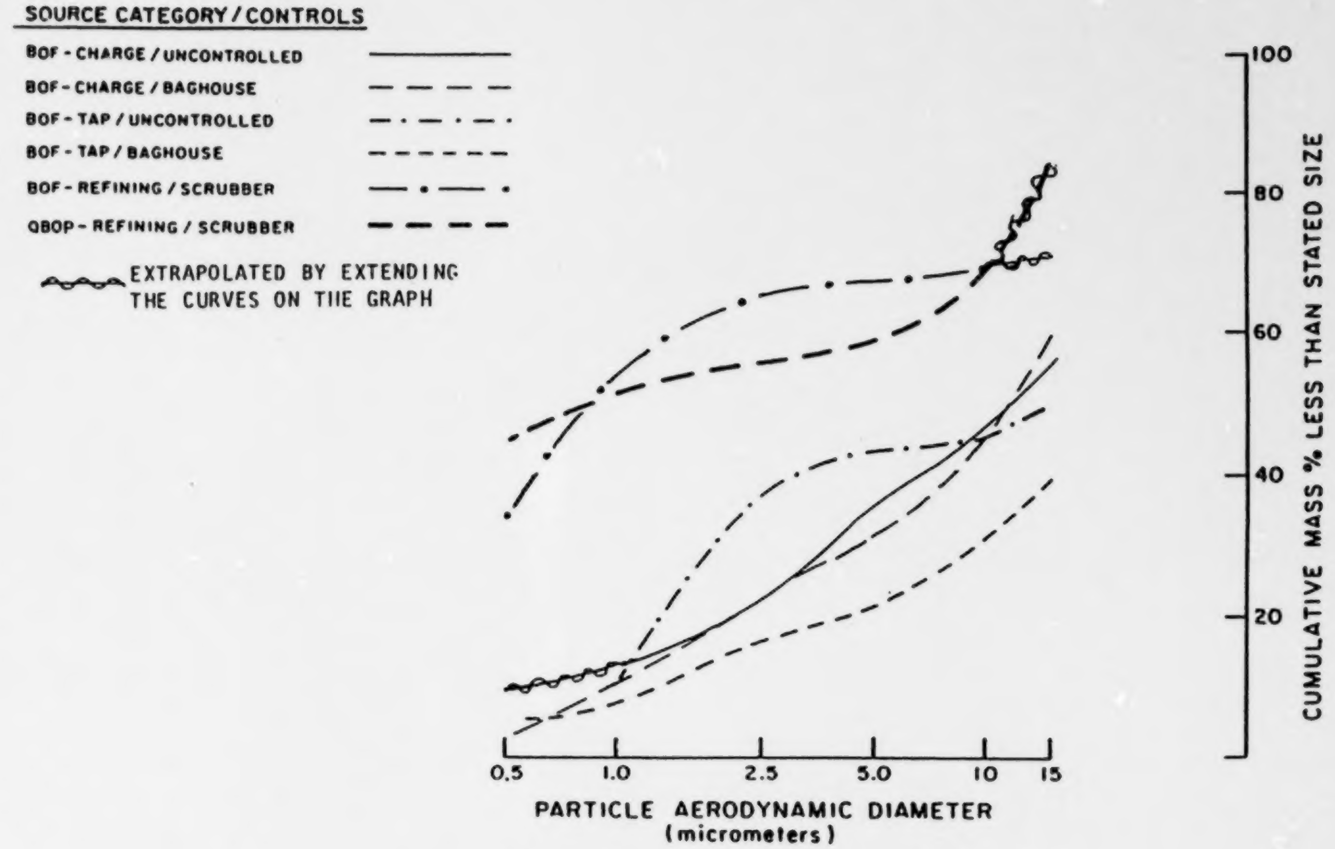
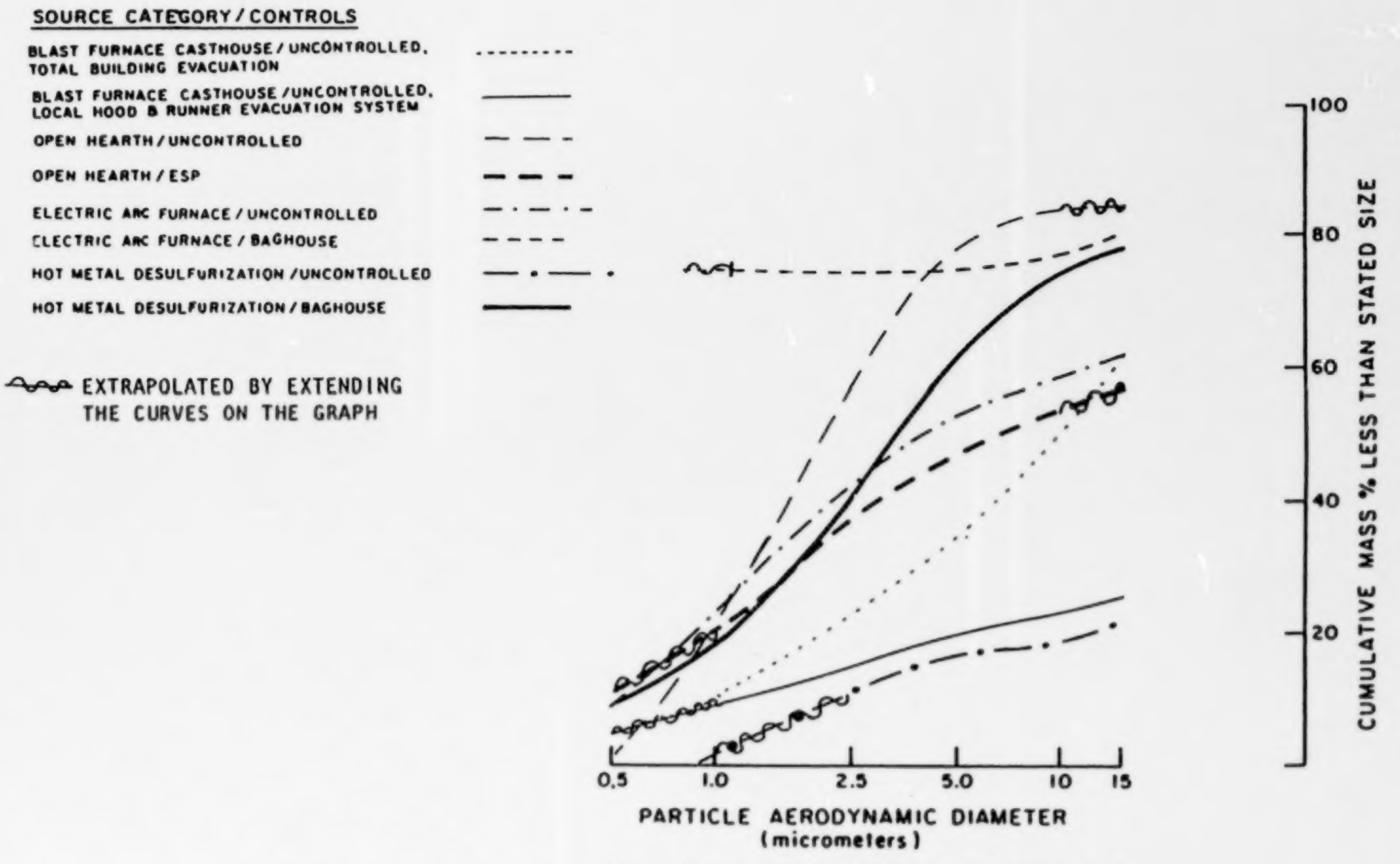


Figure 7.5-2. Particle size distribution of sinter plant emissions.



(Calculated according to the Task Group Lung Dynamics definition of Aerodynamic Diameter)

Figure 7.5-3. Particle size distribution of basic oxygen furnace emissions.



(Calculated according to the Task Group Lung Dynamics definition of Aerodynamic Diameter)

Figure 7.5-4. Particle size distribution of blast furnace, open hearth, electric arc furnace and hot metal desulfurization emissions.

TABLE 7.5-3. UNCONTROLLED CARBON MONOXIDE EMISSION FACTORS FOR IRON AND STEEL MILLS[a]

EMISSION FACTOR RATING: C

Source	kg/Mg	lb/ton
Sintering windbox[b]	22	44
Basic oxygen furnace[c]	69	138
Electric arc furnace[c]	9	18

[a] Reference 6.

[b] kg/Mg (lb/ton) of finished sinter.

[c] kg/Mg (lb/ton) of finished steel.

7.5.2.9 Open Dust Sources - Like process emission sources, open dust sources contribute to the atmospheric particulate burden. Open dust sources include vehicle traffic on paved and unpaved roads, raw material handling outside of buildings and wind erosion from storage piles and exposed terrain. Vehicle traffic consists of plant personnel and visitor vehicles, plant service vehicles, and trucks handling raw materials, plant deliverables, steel products and waste materials. Raw materials are handled by clamshell buckets, bucket/ladder conveyors, rotary railroad dumps, bottom railroad dumps, front end loaders, truck dumps, and conveyor transfer stations, all of which disturb the raw material and expose fines to the wind. Even fine materials resting on flat areas or in storage piles are exposed and are subject to wind erosion. It is not unusual to have several million tons of raw materials stored at a plant and to have in the range of 10 to 100 acres of exposed area there.

Open dust source emission factors for iron and steel production are presented in Table 7.5-4. These factors were determined through source testing at various integrated iron and steel plants.

As an alternative to the single valued open dust emission factors given in Table 7.5-4, empirically derived emission factor equations are presented in Section 11.2 of this document. Each equation was developed for a source operation defined on the basis of a single dust generating mechanism which crosses industry lines, such as vehicle traffic on unpaved roads. The predictive equation explains much of the observed variance in measured emission factors by relating emissions to parameters which characterize source conditions. These parameters may be grouped into three categories: (1) measures of source activity or energy expended (e. g., the speed and weight of a vehicle traveling on an unpaved road), (2) properties of the material being disturbed (e. g., the content of suspendible fines in the surface material on an unpaved road) and (3) climatic parameters (e. g., number of precipitation free days per year, when emissions tend to a maximum).[4]

TABLE 7.5-4. UNCONTROLLED PARTICULATE EMISSION FACTORS FOR OPEN DUST SOURCES AT IRON AND STEEL MILLS[a]

Operation	Emissions by particle size range (aerodynamic diameter)					Units[b]	Emission Factor Rating
	≤ 30 μm	≤ 15 μm	≤ 10 μm	≤ 5 μm	≤ 2.5 μm		
Continuous drop							
Conveyor transfer station sinter[c]	13	9.0	6.5	4.2	2.3	g/Mg	D
	0.026	0.018	0.013	0.0084	0.0046	lb/ton	D
Pile formation stacker pellet ore[c]	1.2	0.75	0.55	0.32	0.17	g/Mg	B
	0.0024	0.0015	0.0011	0.00064	0.00034	lb/ton	B
Lump ore[c]	0.15	0.095	0.075	0.040	0.022	g/Mg	C
	0.00030	0.00019	0.00015	0.000081	0.000043	lb/ton	C
Coal[d]	0.055	0.034	0.026	0.014	0.0075	g/Mg	E
	0.00011	0.000068	0.000052	0.000028	0.000015	lb/ton	E
Batch drop							
Front end loader/truck[c]							
High silt slag	13	8.5	6.5	4.0	2.3	g/Mg	C
	0.026	0.017	0.013	0.0080	0.0046	lb/ton	C
Low silt slag	4.4	2.9	2.2	1.4	0.80	g/Mg	C
	0.0088	0.0058	0.0043	0.0028	0.0016	lb/ton	C
Vehicle travel on unpaved roads							
Light duty vehicle[d]	0.51	0.37	0.28	0.18	0.10	Kg/VKT	C
	1.8	1.3	1.0	0.64	0.36	lb/VMT	C
Medium duty vehicle[d]	2.1	1.5	1.2	0.70	0.42	Kg/VKT	C
	7.3	5.2	4.1	2.5	1.5	lb/VMT	C
Heavy duty vehicle[d]	3.9	2.7	2.1	1.4	0.76	Kg/VKT	B
	14	9.7	7.6	4.8	2.7	lb/VMT	B
Vehicle travel on paved roads							
Light/heavy vehicle mix[c]	0.22	0.16	0.12	0.079	0.042	Kg/VKT	C
	0.78	0.58	0.44	0.28	0.15	lb/VMT	C

[a] Predictive emission factor equations are generally preferred over these single values emission factors. Predictive emission factors estimates are presented in Chapter 11, Section 11.2. VKT = Vehicle kilometer traveled. VMT = Vehicle mile traveled.

[b] Units/unit of material transferred or units/unit of distance traveled.

[c] Reference 4. Interpolation to other particle sizes will be approximate.

[d] Reference 5. Interpolation to other particle sizes will be approximate.

Because the predictive equations allow for emission factor adjustment to specific source conditions, the equations should be used in place of the factors in Table 7.5-4, if emission estimates for sources in a specific iron and steel facility are needed. However, the generally higher quality ratings assigned to the equations are applicable only if (1) reliable values of correction parameters have been determined for the specific sources of interest and (2) the correction parameter values lie within the ranges tested in developing the equations. Section 11.2 lists measured properties of aggregate process materials and road surface materials in the iron and steel industry, which can be used to estimate correction parameter values for the predictive emission factor equations, in the event that site specific values are not available.

Use of mean correction parameter values from Section 11.2 reduces the quality ratings of the emission factor equation by one level.

References for Section 7.5

1. J. Jeffery and J. Vay, Source Category Report for the Iron and Steel Industry, EPA-600/7-86-036, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1986.

2. H. E. McGannon, ed., The Making, and Shaping and Treating of Steel, U. S. Steel Corporation, Pittsburgh, PA, 1971.

3. T. A. Cuscino, Jr., Particulate Emission Factors Applicable to the Iron and Steel Industry, EPA-450/4-79-028, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1979.

4. R. Bohn, et al., Fugitive Emissions from Integrated Iron and Steel Plants, EPA-600/2-78-050, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1978.

5. C. Cowherd, Jr., et al., Iron and Steel Plant Open Source Fugitive Emission Evaluation, EPA-600/2-79-103, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1979.

6. Control Techniques for Carbon Monoxide Emissions from Stationary Sources, AP-65, U. S. Department of Health, Education and Welfare, Washington, DC, March 1970.

7.13 STEEL FOUNDRIES

7.13.1 Process Description[1]

Steel foundries produce steel castings by the melting, alloying and molding of pig iron and steel scrap. The process flow diagram of a typical steel foundry is presented in Figure 7.13-1. The major processing operations of the typical steel foundry are raw materials handling, metal melting, mold and core production, and casting and finishing.

Raw Materials Handling - The raw material handling operations include the receiving, unloading, storage and conveying of all raw materials for the foundry. Some of the raw materials used by steel foundries are pig iron, iron and steel scrap, foundry returns, metal turnings, alloys, carbon additives, fluxes (limestone, soda ash, fluorspar, calcium carbide), sand, sand additives, and binders. These raw materials are received in ships, railcars, trucks, and containers, and are transferred by trucks, loaders, and conveyors to both open pile and enclosed storage areas. They are then transferred by similar means from storage to the subsequent processes.

Metal Melting - Generally, the first step in the metal melting operations is scrap preparation. Since scrap is normally purchased in the proper size for furnace feed, preparation primarily consists of scrap degreasing. This is very important for electric induction furnaces, as organics on scrap can be explosive. Scrap may be degreased with solvents, by centrifugation or by incinerator or preheater combustion. After preparation, the scrap, metal, alloy, and flux are weighed and charged to the furnace.

Electric arc furnaces are used almost exclusively in the steel foundry for melting and formulating steel. Electric arc furnaces are large refractory lined steel pots, fitted with a refractory roof through which three graphite electrodes are inserted. The metal charge is melted with resistive heating generated by electrical current flowing among the electrodes and through the charge. Electric arc furnaces are charged with raw materials by removing the lid, through a chute opening in the lid, or through a door in the side. The molten metal is tapped by tilting and pouring through a hole in the side. Melting capacities range up to 10 megagrams (11 tons) per hour.

A second, less common, furnace used in steel foundries is the open hearth furnace, a very large shallow refractory lined vessel which is operated in a batch manner. The open hearth furnace is fired at alternate ends, using the heat from the waste combustion gases to heat the incoming combustion air.

A third furnace used in the steel foundry is the induction furnace. Induction furnaces are vertical refractory lined cylinders

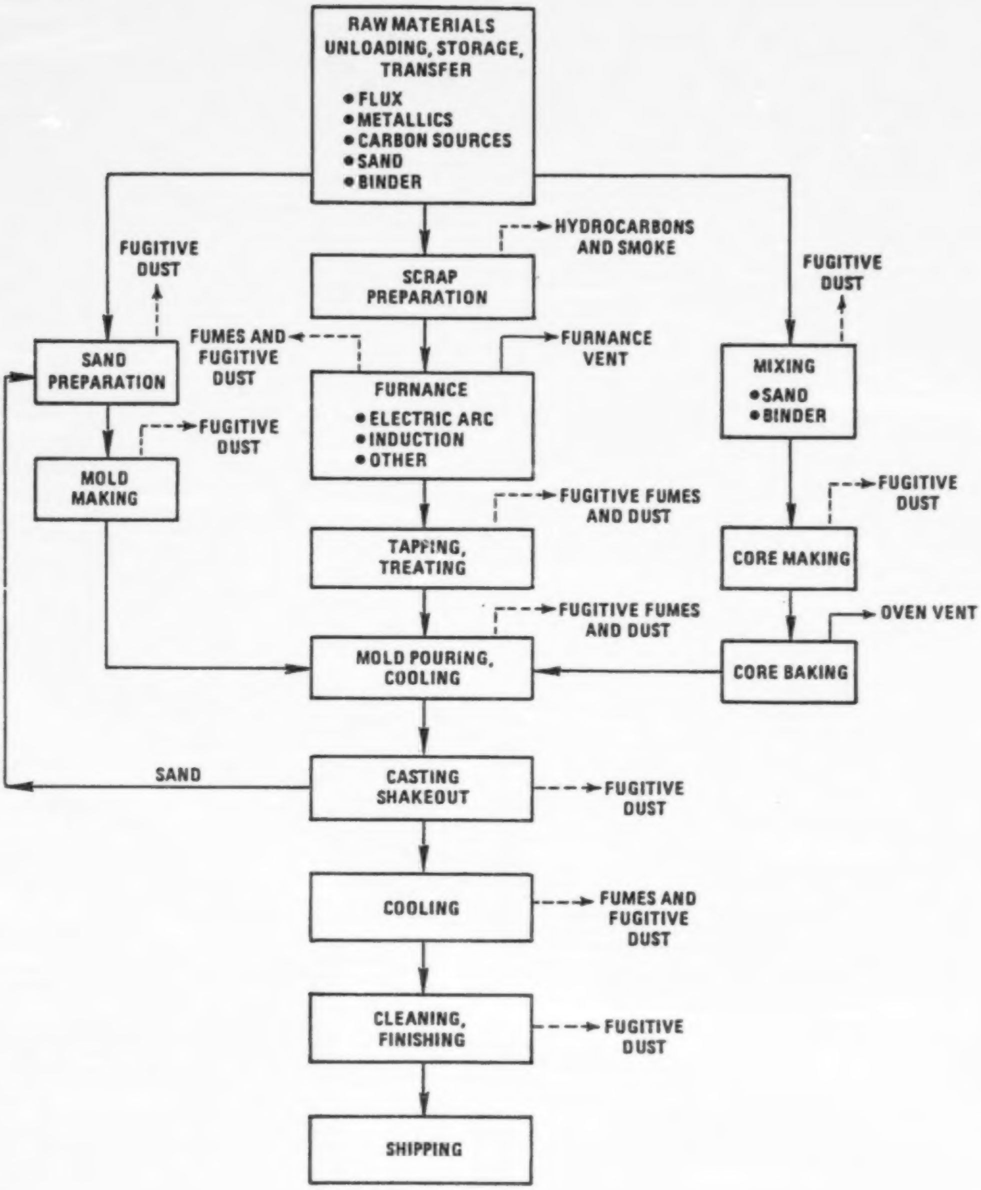

RAW MATERIALS UNLOADING, STORAGE, TRANSFER
• FLUX
• METALLICS
• CARBON SOURCES
• SAND
• BINDER
HYDROCARBONS AND SMOKE
SCRAP PREPARATION
FUGITIVE DUST
SAND PREPARATION
FUMES AND FUGITIVE DUST
FURNANCE VENT
FURNANCE
• ELECTRIC ARC
• INDUCTION
• OTHER
FUGITIVE DUST
MIXING
• SAND
• BINDER
FUGITIVE DUST
MOLD MAKING
FUGITIVE FUMES AND DUST
TAPPING, TREATING
FUGITIVE DUST
CORE MAKING
FUGITIVE FUMES AND DUST
OVEN VENT
MOLD POURING, COOLING
CORE BAKING
SAND
CASTING SHAKEOUT
FUGITIVE DUST
COOLING
FUMES AND FUGITIVE DUST
CLEANING, FINISHING
FUGITIVE DUST
SHIPPING

Figure 7.13-1. Typical flow diagram of a steel foundry.

surrounded by electrical coils energized with alternating current. The resulting fluctuating magnetic field heats the metal. Induction furnaces are kept closed except when charging, skimming and tapping. The molten metal is tapped by tilting and pouring through a hole in the side. Induction furnaces are also used with other furnaces, to hold and superheat a charge melted and refined in the other furnaces. A very small fraction of the secondary steel industry also uses crucible and pneumatic converter furnaces.

The basic melting process operations are 1) furnace charging, in which metal, scrap, alloys, carbon, and flux are added to the furnace, 2) melting, during which the furnace remains closed, 3) backcharging, which is the addition of more metal and possibly alloys, 4) refining, during which the carbon content is adjusted, 5) oxygen lancing, which is injecting oxygen into the molten steel to dislodge slag and to adjust the chemistry of the metal, 6) slag removal, and 7) tapping the molten metal into a ladle or directly into molds.

Mold and Core Production - Cores are forms used to make the internal voids in castings, and molds are forms used to shape the casting exterior. Cores are made of sand with organic binders, molded into a core and baked in an oven. Molds are made of wet sand with clay and organic additives, dried with hot air. Increasingly, coal setting binders are being used in both core and mold production. Used sand from castings shakeout operations is recycled to the sand preparation area, where it is cleaned, screened and reused.

Casting and Finishing - When the melting process is complete, the molten metal is tapped and poured into a ladle. At this time, the molten metal may be treated by adding alloys and/or other chemicals. The treated metal is then poured into molds and is allowed partially to cool under carefully controlled conditions. Molten metal may be poured directly from the furnace to the mold.

When partially cooled, the castings are placed on a vibrating grid, and the sand of the mold and core are shaken away from the casting. The sand is recycled to the mold manufacturing process, and the casting is allowed to cool further.

In the cleaning and finishing process, burrs, risers and gates are broken or ground off to match the contour of the casting. Afterward, the castings are usually shot blasted to remove remaining mold sand and scale.

7.13.2 Emissions and Controls[1]

Emissions from the raw materials handling operations are fugitive particulates generated from receiving, unloading, storage and conveying all raw materials for the foundry. These emissions are controlled by enclosing the major emission points and routing the air from the enclosures through fabric filters.

Emissions from scrap preparation consist of hydrocarbons if solvent degreasing is used, and consist of smoke, organics and carbon monoxide if heating is used. Catalytic incinerators and afterburners of approximately 95 percent control efficiency for carbon monoxide and organics can be applied to these sources.

Emissions from melting furnaces are particulates, carbon monoxide, organics, sulfur dioxide, nitrogen oxides, and small quantities of chlorides and fluorides. The particulates, chlorides and fluorides are generated by the flux, the carbon additives, and dirt and scale on the scrap charge. Organics on the scrap and the carbon additives effect CO emissions. The highest concentrations of furnace emissions occur during charging, backcharging, alloying, oxygen lancing, slag removal, and tapping operations, when the furnace lids and doors are opened. Characteristically, these emissions have escaped into the furnace building and have been vented through roof vents. Controls for emissions during the melting and refining operations focus on venting the furnace gases and fumes directly to an emission collection duct and control system. Controls for fugitive furnace emissions involve either the use of building roof hoods or of special hoods near the furnace doors, to collect emissions and route them to emission control systems. Emission control systems commonly used to control particulate emissions from electric arc and induction furnaces are bag filters, cyclones and venturi scrubbers. The capture efficiencies of the collection systems, presented in Table 7.13-1, range from 80 to 100 percent. Usually, induction furnaces are uncontrolled.

The major pollutants from mold and core production are particulates from sand reclaiming, sand preparation, sand mixing with binders and additives, and mold and core forming. There are volatile organics (VOC), CO and particulate emissions from core baking, and VOC emissions from mold drying. Bag filters and high energy scrubbers can be used to control particulates from mold and core production. Afterburners and catalytic incinerators can be used to control VOC and CO emissions.

In the casting operations, large quantities of particulates can be generated in the steps prior to pouring. Emissions from pouring consist of fumes, CO, VOC, and particulates from the mold and core materials when contacted by the molten steel. As the mold cools, emissions continue. A significant quantity of particulate emissions is also generated during the casting shakeout operation. The particulate emissions from the shakeout operations can be controlled by either high efficiency cyclones or bag filters. Emissions from pouring are usually uncontrolled.

Emissions from finishing operations consist of large particulates from the removal of burrs, risers and gates, and during shot blasting. Particulates from finishing operations typically are large and are generally controlled by cyclones.

TABLE 7.13-1. EMISSION FACTORS FOR STEEL FOUNDRIES

EMISSION FACTOR RATING: A

Process	Particulates[a] kg/Mg	Particulates[a] lb/ton	Nitrogen oxides kg/Mg	Nitrogen oxides lb/ton
Melting				
Electric arc[b,c]	6.5 (2 to 20)	13 (4 to 40)	0.1	0.2
Open hearth[d,e]	5.5 (1 to 10)	11 (2 to 20)	0.005	0.01
Open hearth oxygen lanced[f,g]	5 (4 to 5.5)	10 (8 to 11)	-	-
Electric induction[h]	0.05	0.1	-	-

[a] Expressed as units per unit weight of metal processed. If the scrap metal is very dirty or oily, or if increased oxygen lancing is employed, the emission factor should be chosen from the high side of the factor range.

[b] Electrostatic precipitator, 92 - 98% control efficiency; baghouse (fabric filter), 98 - 99% control efficiency; venturi scrubber, 94 - 98% control efficiency.

[c] References 2 - 10.

[d] Electrostatic precipitator, 95 - 98.5% control efficiency; baghouse, 99.9% control efficiency; venturi scrubber, 96 - 99% control efficiency.

[e] References 2, 11 - 13.

[f] Electrostatic precipitator, 95 - 98% control efficiency; baghouse, 99% control efficiency; venturi scrubber, 95 - 98% control efficiency.

[g] References 6 and 14.

[h] Usually not controlled.

Emission factors for melting furnaces in the steel foundry are presented in Table 7.13-1.

Although no emission factors are available for nonfurnace emission sources in steel foundries, they are very similar to those in iron foundries.[1] Nonfurnace emission factors and particle size distributions for iron foundry emission sources are presented in Section 7.10, Gray Iron Foundries.

References for Section 7.13

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11.2.1 UNPAVED ROADS

11.2.1.1 General

Dust plumes trailing behind vehicles traveling on unpaved roads are a familiar sight in rural areas of the United States. When a vehicle travels an unpaved road, the force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed.

11.2.1.2 Emissions Calculation And Correction Parameters

The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. Also, field investigations have shown that emissions depend on correction parameters (average vehicle speed, average vehicle weight, average number of wheels per vehicle, road surface texture and road surface moisture) that characterize the condition of a particular road and the associated vehicle traffic.[1-4]

Dust emissions from unpaved roads have been found to vary in direct proportion to the fraction of silt (particles smaller than 75 micrometers in diameter) in the road surface materials.[1] The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200 mesh screen, using the ASTM-C-136 method. Table 11.2.1-1 summarizes measured silt values for industrial and rural unpaved roads.

The silt content of a rural dirt road will vary with location, and it should be measured. As a conservative approximation, the silt content of the parent soil in the area can be used. However, tests show that road silt content is normally lower than in the surrounding parent soil, because the fines are continually removed by the vehicle traffic, leaving a higher percentage of coarse particles.

Unpaved roads have a hard, generally nonporous surface that usually dries quickly after a rainfall. The temporary reduction in emissions caused by precipitation may be accounted for by not considering emissions on "wet" days (more than 0.254 millimeters [0.01 inches] of precipitation).

The following empirical expression may be used to estimate the quantity of size specific particulate emissions from an unpaved road, per vehicle kilometer traveled (VKT) or vehicle mile traveled (VMT), with a rating of A:

$$E = k(1.7)\left(\frac{s}{12}\right)\left(\frac{S}{48}\right)\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right) \quad \text{(kg/VKT)}$$

$$E = k(5.9)\left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right) \quad \text{(lb/VMT)}$$

TABLE 11.2.1-1. TYPICAL SILT CONTENT VALUES OF SURFACE MATERIAL ON INDUSTRIAL AND RURAL UNPAVED ROADS[a]

Industry	Road use or surface material	Plant sites	Test samples	Silt (wgt. %)	
				Range	Mean
Copper smelting	Plant road	1	3	15.9 - 19.1	17.0
Iron and steel production	Plant road	9	20	4.0 - 16.0	8.0
Sand and gravel processing	Plant road	1	3	4.1 - 6.0	4.8
Stone quarrying and processing	Plant road	1	5	10.5 - 15.6	14.1
Taconite mining and processing	Haul road	1	12	3.7 - 9.7	5.8
	Service road	1	8	2.4 - 7.1	4.3
Western surface coal mining	Access road	2	2	4.9 - 5.3	5.1
	Haul road	3	21	2.8 - 18	8.4
	Scraper road	3	10	7.2 - 25	17
	Haul road (freshly graded)	2	5	18 - 29	24
Rural roads	Gravel	1	1	NA	5.0
	Dirt	2	5	5.8 - 68	28.5
	Crushed limestone	2	8	7.7 - 13	9.6

[a] References 4-11. NA = Not available.

where: E = emission factor
k = particle size multiplier (dimensionless)
s = silt content of road surface material (%)
S = mean vehicle speed, km/hr (mph)
W = mean vehicle weight, Mg (ton)
w = mean number of wheels
p = number of days with at least 0.254 mm (0.01 in.) of precipitation per year

The particle size multiplier, k, in the equation varies with aerodynamic particle size range as follows:

Aerodynamic Particle Size Multiplier For Equation

≤30 um[a]	≤30 um	≤15 um	≤10 um	≤5um	≤2.5 um
1.0	0.80	0.50	0.36	0.20	0.095

[a] Stokes diameter

The number of wet days per year, p, for the geographical area of interest should be determined from local climatic data. Figure 11.2.1-1 gives the geographical distribution of the mean annual number of wet days per year in the United States.

The equation retains the assigned quality rating, if applied within the ranges of source conditions that were tested in developing the equation, as follows:

Ranges Of Source Conditions For Equation

Road silt content (wgt. %)	Mean vehicle weight		Mean vehicle speed		mean no. of wheels
	Mg	ton	km/hr	mph	
4.3 - 20	2.7 - 142	3 - 157	21 - 64	13 - 40	4 - 13

Also, to retain the quality rating of the equation when addressing a specific unpaved road, it is necessary that reliable correction parameter values be determined for the road in question. The field and laboratory procedures for determining road surface silt content are given in Reference 4. In the event that site specific values for correction parameters cannot be obtained, the appropriate mean values from Table 11.2.1-1 may be used, but the quality rating of the equation is reduced to B.

The equation was developed for calculating annual average emissions, and thus, is to be multiplied by annual vehicle distance traveled (VDT). Annual average values for each of the correction parameters are to be substituted for the equation. Worst case emissions, corresponding to dry road conditions, may be calculated by setting p = 0 in the equation (equivalent to dropping the last

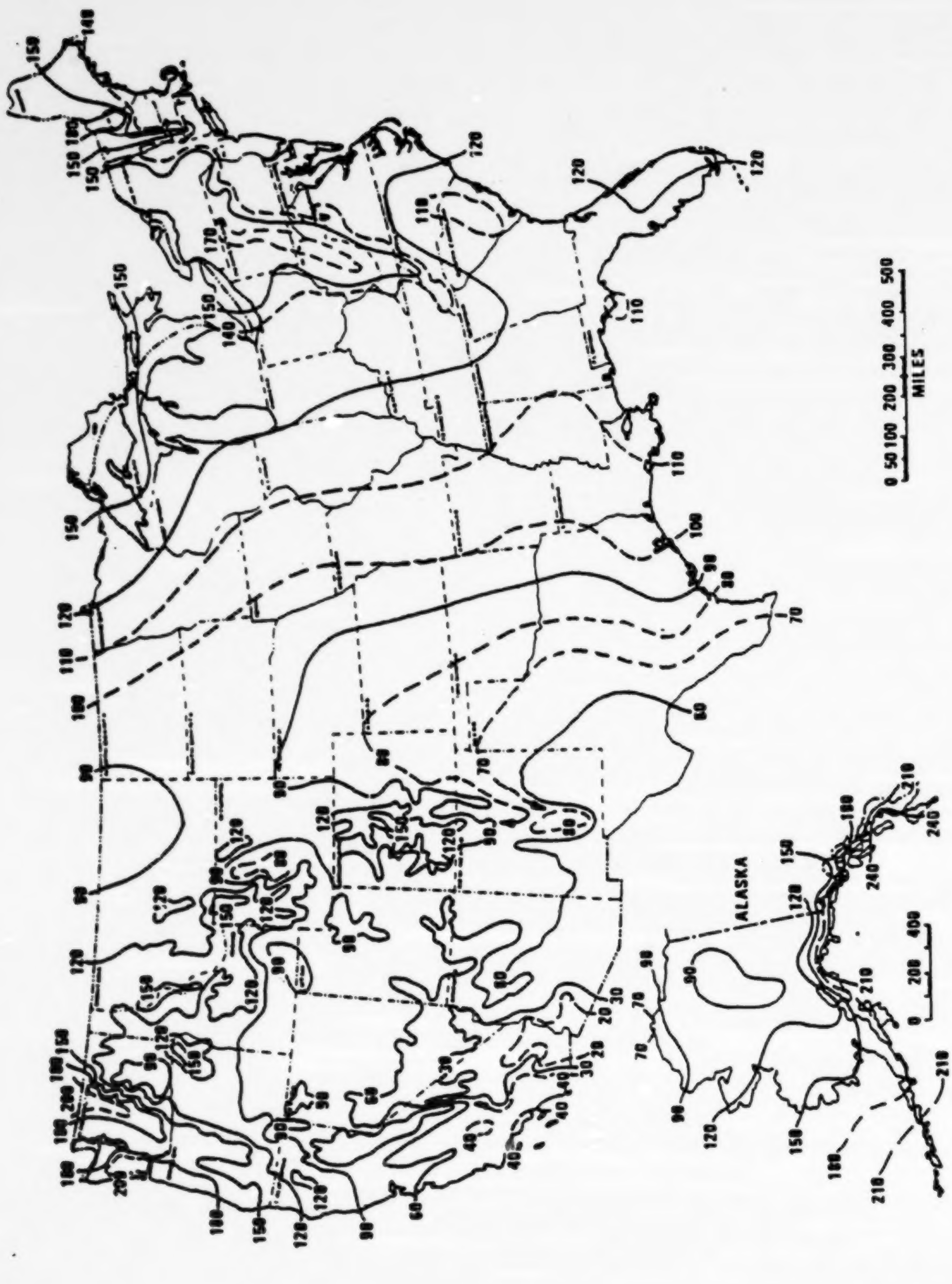
0 50 100 200 300 400 500
MILES
ALASKA
0 200 400

Figure 11.2.1-1. Mean number of days with 0.01 inch or more of precipitation in United States.[10]

term from the equation). A separate set of nonclimatic correction parameters and a higher than normal VDT value may also be justified for the worst case average period (usually 24 hours). Similarly, in using the equation to calculate emissions for a 91 day season of the year, replace the term (365-p)/365 with the term (91-p)/91, and set p equal to the number of wet days in the 91 day period. Also, use appropriate seasonal values for the nonclimatic correction parameters and for VDT.

11.2.1.3 Controls

Common control techniques for unpaved roads are paving, surface treating with penetration chemicals, working into the roadbed of stabilization chemicals, watering, and traffic control regulations. Chemical stabilizers work either by binding the surface material or by enhancing moisture retention. Paving, as a control technique, is often not economically practical. Surface chemical treatment and watering can be accomplished with moderate to low costs, but frequent retreatments are required. Traffic controls, such as speed limits and traffic volume restrictions, provide moderate emission reductions but may be difficult to enforce. The control efficiency obtained by speed reduction can be calculated using the predictive emission factor equation given above.

The control efficiencies achievable by paving can be estimated by comparing emission factors for unpaved and paved road conditions, relative to airborne particle size range of interest. The predictive emission factor equation for paved roads, given in Section 11.2.6, requires estimation of the silt loading on the traveled portion of the paved surface, which in turn depends on whether the pavement is periodically cleaned. Unless curbing is to be installed, the effects of vehicle excursion onto shoulders (berms) also must be taken into account in estimating control efficiency.

The control efficiencies afforded by the periodic use of road stabilization chemicals are much more difficult to estimate. The application parameters which determine control efficiency include dilution ratio, application intensity (mass of diluted chemical per road area) and application frequency. Other factors that affect the performance of chemical stabilizers include vehicle characteristics (e. g., traffic volume, average weight) and road characteristics (e. g., bearing strength).

Besides water, petroleum resin products have historically been the dust suppressants most widely used on industrial unpaved roads. Figure 11.2.1-2 presents a method to estimate average control efficiencies associated with petroleum resins applied to unpaved roads. Several items should be noted:

1. The term "ground inventory" represents the total volume (per unit area) of petroleum resin concentrate (not solution) applied since the start of the dust control season.

2. Because petroleum resin products must be periodically reapplied to unpaved roads, the use of a time-averaged control efficiency value is appropriate. Figure 11.2.1-2 presents control efficiency values averaged over two common application intervals, two weeks and one month. Other application intervals will require interpolation.

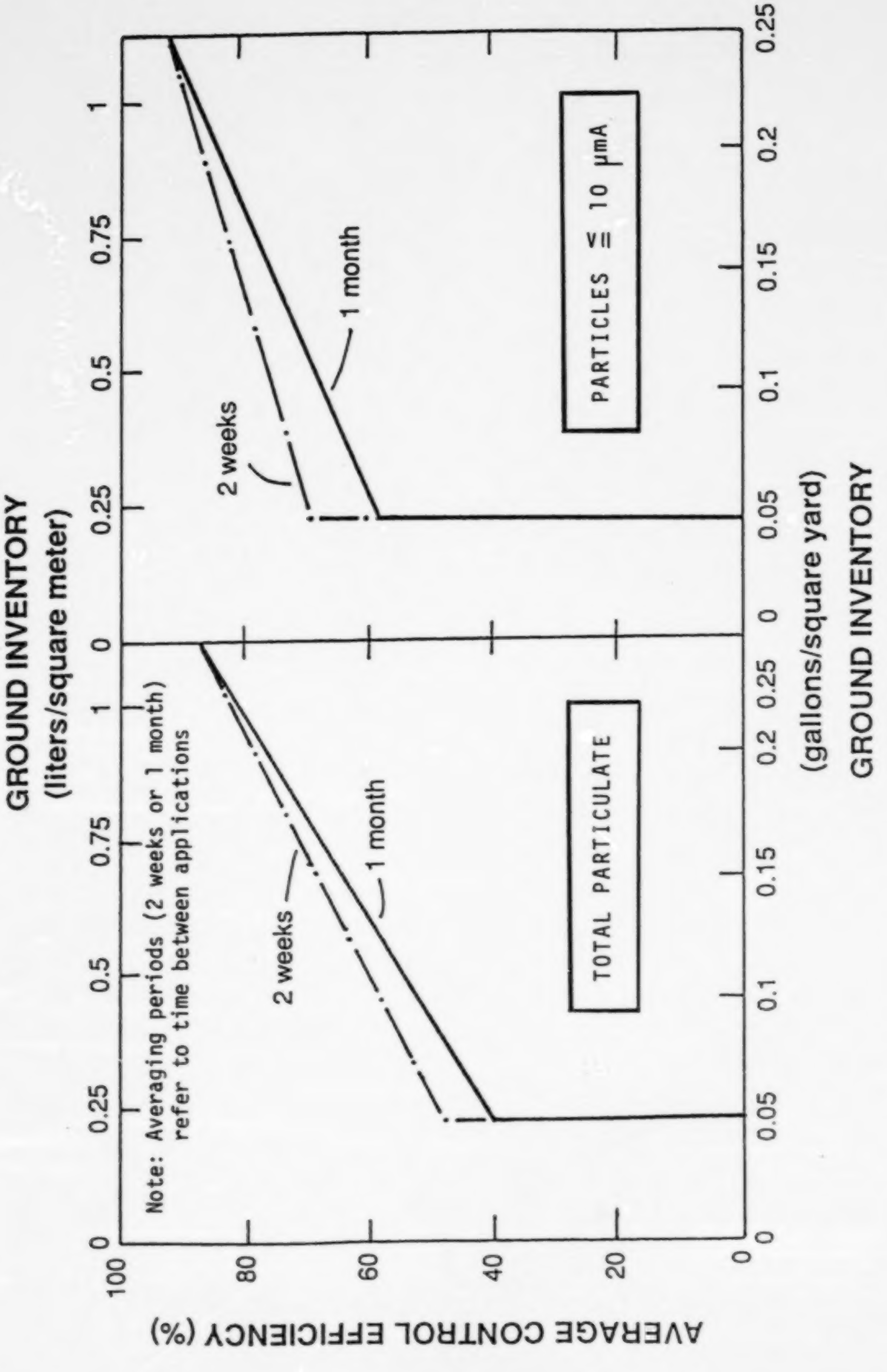

Figure 11.2.1-2. Average control efficiencies over common application intervals.

3. Note that zero efficiency is assigned until the ground inventory reaches 0.2 liters per square meter (0.05 gallons per square yard).

As an example of the use of Figure 11.2.1-2, suppose that the equation has been used to estimate an emission factor of 2.0 kilograms per vehicle kilometer traveled for particles equal to or less than 10 microns from a particular road. Also, suppose that, starting on May 1, the road is treated with 1 liter per square meter of a (1 part petroleum resin to 5 parts water) solution on the first of each month until October. Then, the following average controlled emission factors are found:

Period	Ground Inventory (L/m^2)	Average Control Efficiency[a] (%)	Average Controlled Emission Factor (kg/VKT)
May	0.17	0	2.0
June	0.33	62	0.76
July	0.50	68	0.64
August	0.67	74	0.52
September	0.83	80	0.40

[a] From Figure 11.2.1-2, $\leq$ 10 um. Zero efficiency assigned if ground inventory is less than 0.2 L/m^2 (0.05 gal/yd^2).

Newer dust suppressants have been successful in controlling emissions from unpaved roads. Specific test results for those chemicals, as well as for petroleum resins, are provided in References 14 through 16.

References for Section 11.2.1

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8. T. Cuscino, Jr., et al., Taconite Mining Fugitive Emissions Study, Minnesota Pollution Control Agency, Roseville, MN, June 1979.

9. K. Axetell and C. Cowherd, Jr., Improved Emission Factors For Fugitive Dust From Western Surface Coal Mining Sources, 2 Volumes, EPA Contract No. 68-03-2924, PEI, Inc., Kansas City, MO, July 1981.

10. T. Cuscino, Jr., et al., Iron And Steel Plant Open Source Fugitive Emission Control Evaluation, EPA-600/2-83-110, U. S. Environmental Protection Agency, Cincinnati, OH, October 1983.

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11.2.3 AGGREGATE HANDLING AND STORAGE PILES

11.2.3.1 General

Inherent in operations that use minerals in aggregate form is the maintenance of outdoor storage piles. Storage piles are usually left uncovered, partially because of the need for frequent material transfer into or out of storage.

Dust emissions occur at several points in the storage cycle, such as during material loading onto the pile, disturbances by strong wind currents, and loadout from the pile. The movement of trucks and loading equipment in the storage pile area is also a substantial source of dust.

11.2.3.2 Emissions And Correction Parameters

The quantity of dust emissions from aggregate storage operations varies with the volume of aggregate passing through the storage cycle. Also, emissions depend on three parameters of the condition of a particular storage pile: age of the pile, moisture content and proportion of aggregate fines.

When freshly processed aggregate is loaded onto a storage pile, its potential for dust emissions is at a maximum. Fines are easily disaggregated and released to the atmosphere upon exposure to air currents, either from aggregate transfer itself or from high winds. As the aggregate weathers, however, potential for dust emissions is greatly reduced. Moisture causes aggregation and cementation of fines to the surfaces of larger particles. Any significant rainfall soaks the interior of the pile, and the drying process is very slow.

Silt (particles equal to or less than 75 microns in diameter) content is determined by measuring the portion of dry aggregate material that passes through a 200 mesh screen, using ASTM-C-136 method. Table 11.2.3-1 summarizes measured silt and moisture values for industrial aggregate materials.

11.2.3.3 Predictive Emission Factor Equations

Total dust emissions from aggregate storage piles are contributions of several distinct source activities within the storage cycle:

1. Loading of aggregate onto storage piles (batch or continuous drop operations).
2. Equipment traffic in storage area.
3. Wind erosion of pile surfaces and ground areas around piles.
4. Loadout of aggregate for shipment or for return to the process stream (batch or continuous drop operations).

Adding aggregate material to a storage pile or removing it both usually involve dropping the material onto a receiving surface. Truck dumping on the pile or loading out from the pile to a truck with a front end loader are examples of batch drop operations. Adding material to the pile by a conveyor stacker is an example of a continuous drop operation.

TABLE 11.2.3-1. TYPICAL SILT AND MOISTURE CONTENT VALUES OF MATERIALS AT VARIOUS INDUSTRIES

Industry	Material	Silt (%)			Moisture (%)		
		No. of test samplers	Range	Mean	No. of test samplers	Range	Mean
Iron and steel production[a]	Pellet ore	10	1.4 - 13	4.9	8	0.64 - 3.5	2.1
	Lump ore	9	2.8 - 19	9.5	6	1.6 - 8.1	5.4
	Coal	7	2 - 7.7	5	6	2.8 - 11	4.8
	Slag	3	3 - 7.3	5.3	3	0.25 - 2.2	0.92
	Flue dust	2	14 - 23	18.0	0	NA	NA
	Coke breeze	1		5.4	1		6.4
	Blended ore	1		15.0	1		6.6
	Sinter	1		0.7	0	NA	NA
	Limestone	1		0.4	0	NA	NA
Stone quarrying and processing[b]	Crushed limestone	2	1.3 - 1.9	1.6	2	0.3 - 1.1	0.7
Taconite mining and processing[c]	Pellets	9	2.2 - 5.4	3.4	7	0.05 - 2.3	0.9
	Tailings	2	NA	11.0	1		0.35
Western surface coal mining[d]	Coal	15	3.4 - 16	6.2	7	2.8 - 20	6.9
	Overburden	15	3.8 - 15	7.5	0	NA	NA
	Exposed ground	3	5.1 - 21	15.0	3	0.8 - 6.4	3.4
Coal fired power generation[e]	Coal	60	0.6 - 4.8	2.2	59	2.7 - 7.4	4.5

[a] References 2-5. NA = not applicable.
[b] Reference 1.
[c] Reference 6.
[d] Reference 7.
[e] Reference 8. Values reflect "as received" conditions of a single power plant.

The quantity of particulate emissions generated by either type of drop operation, per ton of material transferred, may be estimated, with a rating of A, using the following empirical expression[2]:

$$E = k(0.0016)\ \frac{\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}}\ (\text{kg/Mg})$$

$$E = k(0.0032)\ \frac{\left(\frac{U}{5}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}}\ (\text{lb/ton})$$

where: E = emission factor
k = particle size multiplier (dimensionless)
U = mean wind speed, m/s (mph)
M = material moisture content (%)

The particle size multiplier, k, varies with aerodynamic particle diameter, as shown in Table 11.2.3-2.

TABLE 11.2.3-2. AERODYNAMIC PARTICLE SIZE MULTIPLIER (k)

<30 um	<15 um	<10 um	<5 um	<2.5 um
0.74	0.48	0.35	0.20	0.11

The equation retains the assigned quality rating if applied within the ranges of source conditions that were tested in developing the equation, as given in Table 11.2.3-3. Note that silt content is included in Table 11.2.3-3, even though silt content does not appear as a correction parameter in the equation. While it is reasonable to expect that silt content and emission factors are interrelated, no significant correlation between the two was found during the derivation of the equation, probably because most tests with high silt contents were conducted under lower winds, and vice versa. It is recommended that estimates from the equation be reduced one quality rating level, if the silt content used in a particular application falls outside the range given in Table 11.2.3-3.

TABLE 11.2.3-3. RANGES OF SOURCE CONDITIONS FOR EQUATION 1

Silt Content	Moisture Content	Wind Speed (m/s)	Wind Speed (mph)
0.44 - 19	0.25 - 4.8	0.6 - 6.7	1.3 - 15

Also, to retain the equation's quality rating when applied to a specific facility, it is necessary that reliable correction parameters be determined for the specific sources of interest. The field and laboratory procedures for aggregate sampling are given in Reference 3. In the event that site specific values for correction parameters cannot be obtained, the appropriate mean values from Table 11.2.3-1 may be used, but, in that case, the quality rating of the equation is reduced by one level.

For emissions from equipment traffic (trucks, front end loaders, dozers, etc.) traveling between or on piles, it is recommended that the equations for vehicle traffic on unpaved surfaces be used (see Section 11.2.1). For vehicle travel between storage piles, the silt value(s) for the areas among the piles (which may differ from the silt values for the stored materials) should be used.

Worst case emissions from storage pile areas occur under dry windy conditions. Worst case emissions from materials handling operations may be calculated by substituting into the equation appropriate values for aggregate material moisture content and for anticipated wind speeds during the worst case averaging period, usually 24 hours. The treatment of dry conditions for vehicle traffic (Section 11.2.1), centering on parameter p, follows the methodology described in Section 11.2.1. Also, a separate set of nonclimatic correction parameters and source extent values corresponding to higher than normal storage pile activity may be justified for the worst case averaging period.

11.2.3.4 Controls

Watering and chemical wetting agents are the principal means for control of aggregate storage pile emissions. Enclosure or covering of inactive piles to reduce wind erosion can also reduce emissions. Watering is useful mainly to reduce emissions from vehicle traffic in the storage pile area. Watering of the storage piles themselves typically has only a very temporary slight effect on total emissions. A much more effective technique is to apply chemical wetting agents for better wetting of fines and longer retention of the moisture film. Continuous chemical treatment of material loaded onto piles, coupled with watering or treatment of roadways, can reduce total particulate emissions from aggregate storage operations by up to 90 percent.[9]

References for Section 11.2.3

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11.2.6 INDUSTRIAL PAVED ROADS

11.2.6.1 General

Various field studies have indicated that dust emissions from industrial paved roads are a major component of atmospheric particulate matter in the vicinity of industrial operations. Industrial traffic dust has been found to consist primarily of mineral matter, mostly tracked or deposited onto the roadway by vehicle traffic itself, when vehicles enter from an unpaved area or travel on the shoulder of the road, or when material is spilled onto the paved surface from open truck bodies.

11.2.6.2 Emissions And Correction Parameters[1-2]

The quantity of dust emissions from a given segment of paved road varies linearly with the volume of traffic. In addition, field investigations have shown that emissions depend on correction parameters (road surface silt content, surface dust loading and average vehicle weight) of a particular road and associated vehicle traffic.

Dust emissions from industrial paved roads have been found to vary in direct proportion to the fraction of silt (particles equal to or less than 75 microns in diameter) in the road surface material. The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200 mesh screen, using the ASTM-C-136 method. In addition, it has also been found that emissions vary in direct proportion to the surface dust loading. The road surface dust loading is that loose material which can be collected by broom sweeping and vacuuming of the traveled portion of the paved road. Table 11.2.6-1 summarizes measured silt and loading values for industrial paved roads.

11.2.6.3 Predictive Emission Factor Equations

The quantity of total suspended particulate emissions generated by vehicle traffic on dry industrial paved roads, per vehicle kilometer traveled (VKT) or vehicle mile traveled (VMT), may be estimated with a rating of B or D (see below), using the following empirical expression[2]:

$$E = 0.022\ I \left(\frac{4}{n}\right) \left(\frac{s}{10}\right) \left(\frac{L}{280}\right) \left(\frac{W}{2.7}\right)^{0.7} \quad \text{(kg/VKT)} \qquad (1)$$

$$E = 0.022\ I \left(\frac{4}{n}\right) \left(\frac{s}{10}\right) \left(\frac{L}{1000}\right) \left(\frac{W}{3}\right)^{0.7} \quad \text{(lb/VMT)}$$

where: E = emission factor
I = industrial augmentation factor (dimensionless) (see below)
n = number of traffic lanes
s = surface material silt content (%)
L = surface dust loading, kg/km (lb/mile) (see below)
W = average vehicle weight, Mg (ton)

TABLE 11.2.6-1. TYPICAL SILT CONTENT AND LOADING VALUES FOR PAVED ROADS AT INDUSTRIAL FACILITIES[a]

Industry	No. of sites	No. of samples	Silt (wgt. %)		No. of travel lanes	Total loading x 10^{-3}			Silt loading (g/m^2)	
			Range	Mean		Range	Mean	Units[b]	Range	Mean
Copper smelting	1	3	15.4 - 21.7	19.0	2	12.9 - 19.5	15.9	kg/km	188 - 400	292
						45.8 - 69.2	55.4	lb/mi		
Iron and steel production	6	20	1.1 - 35.7	12.5	2	0.006 - 4.77	0.495	kg/km	0.09 - 79	12
						0.020 - 16.9	1.75	lb/mi		
Asphalt batching	1	3	2.6 - 4.6	3.3	1	12.1 - 18.0	14.9	kg/km	76 - 193	120
						43.0 - 64.0	52.8	lb/mi		
Concrete batching	1	3	5.2 - 6.0	5.5	2	1.4 - 1.8	1.7	kg/km	11 - 12	12
						5.0 - 6.4	5.9	lb/mi		
Sand and gravel processing	1	3	6.4 - 7.9	7.1	1	2.8 - 5.5	3.8	kg/km	53 - 95	70
						9.9 - 19.4	13.3	lb/mi		

[a] References 1-5.

[b] Multiply entries by 1,000 to obtain stated units.

The industrial road augmentation factor (I) in Equation 1 takes into account higher emissions from industrial roads than from urban roads. $I = 7.0$ for a paved industrial roadway which traffic enters from unpaved areas. $I = 3.5$ for an industrial roadway with unpaved shoulders where 20 percent of the vehicles are forced to travel temporarily with one set of wheels on the shoulder. $I = 1.0$ for cases in which traffic travels only on paved areas. A value between 1.0 and 7.0 which best represents conditions for paved roads at a certain industrial facility should be used for I in the equation.

The equation retains the quality rating of B if applied to vehicles traveling entirely on paved surfaces ($I = 1.0$) and if applied within the range of source conditions that were tested in developing the equation as follows:

Silt content (%)	Surface loading		No. of lanes	Vehicle weight	
	kg/km	lb/mile		Mg	tons
5.1 - 92	42.0 - 2000	149 - 7100	2 - 4	2.7 - 12	3 - 13

If I is less than 1.0, the rating of the equation drops to D, because of the subjectivity in the guidelines for estimating I.

The quantity of particle emissions in the finer size ranges generated by traffic consisting predominately of medium and heavy duty vehicles on dry industrial paved roads, per vehicle unit of travel, may be estimated, with a rating of A, using the equation:

$$E = k \left(\frac{sL}{12}\right)^{0.3} \quad \text{(kg/VKT)} \qquad (2)$$

$$E = k(3.5) \left(\frac{sL}{0.35}\right)^{0.3} \quad \text{(lb/VMT)}$$

where: E = emission factor

sL = road surface silt loading, g/m^2 (oz/yd^2)

The particle size multiplier (k) above varies with aerodynamic size range as follows:

Aerodynamic Particle Size Multiplier (k) For Equation 2 (Dimensionless)		
$\leq$15 um	$\leq$10 um	$\leq$2.5 um
0.28	0.22	0.081

To determine particulate emissions for a specific particle size range, use the appropriate value of k above.

The equation retains the quality rating of A, if applied within the range of source conditions that were tested in developing the equation as follows:

silt loading, 2 - 240 g/m^2 (0.06 - 7.1 oz/yd^2)

mean vehicle weight, 6 - 42 Mg (7 - 46 tons)

The following single valued emission factors[6] may be used in lieu of Equation 2 to estimate particle emissions in the finer size ranges generated by light duty vehicles on dry, heavily loaded industrial roads, with a rating of C:

Emission Factors For Light Duty Vehicles On Heavily Loaded Roads

$\leq$15 um	$\leq$10 um
0.12 kg/VKT (0.41 lb/VMT)	0.093 kg/VKT (0.33 lb/VMT)

These emission factors retain the assigned quality rating, if applied within the range of source conditions that were tested in developing the factors, as follows:

silt loading, 15 - 400 g/m^2 (0.44 - 12 oz/yd^2)

mean vehicle weight, $\leq$4 Mg ($\leq$4 tons)

Also, to retain the quality ratings of Equations 1 and 2 when applied to a specific industrial paved road, it is necessary that reliable correction parameter values for the specific road in question be determined. The field and laboratory procedures for determining surface material silt content and surface dust loading are given in Reference 2. In the event that site specific values for correction parameters cannot be obtained, the appropriate mean values from Table 11.2.6-1 may be used, but the quality ratings of the equation should be reduced by one level.

11.2.6.4 Controls

Common control techniques for industrial paved roads are broom sweeping, vacuum sweeping and water flushing, used alone or in combination. All of these techniques work by reducing the silt loading on the traveled portions of the road. As indicated by a comparison of Equations 1 and 2, fine particle emissions are less sensitive to the value of silt loading than are total suspend particulate emissions. Consistent with this, control techniques are generally less effective for the finer particle sizes.[4] The exception is water flushing, which appears preferentially to remove (or agglomerate) fine particles from the paved road surface. Broom sweeping is generally regarded as the least effective of the common control techniques, because the mechanical sweeping process is inefficient in removing silt from the road surface.

Although there are relatively few quantitative data on emissions from controlled paved roads, those that are available indicate that adequate estimates generally may be obtained by substituting controlled loading values into Equations 1 and 2. The major exception to this is water flushing combined with broom sweeping. In that case, the equations tend to overestimate emissions substantially (by an average factor of 4 or more).

On a paved road with moderate traffic (500 vehicles per day), to achieve control efficiencies on the order of 50 percent, requires cleaning of the surface at least twice per week.[4] This is because of the characteristically rapid buildup of road surface material from spillage and the tracking and deposition of material from adjacent unpaved surfaces, including the shoulders (berms) of the paved road. Because industrial paved roads usually do not have curbs, it is important that the width of the paved road surface be sufficient for vehicles to pass without excursion onto unpaved shoulders. Equation 1 indicates that eliminating vehicle travel on unpaved or untreated shoulders would effect a major reduction in particulate emissions. An even greater effect, by a factor of 7, would result from preventing travel from unpaved roads or parking lots onto the paved road of interest.

References for Section 11.2.6

1. R. Bohn, et al., Fugitive Emissions From Integrated Oron And Steel Plants, EPA-600/2-78-050, U. S. Environmental Protection Agency, Cincinnati, OH, March 1978.

2. C. Cowherd, Jr., et al., Iron And Steel Plant Open Dust Source Fugitive Emission Evaluation, EPA-600/2-79-103, U. S. Environmental Protection Agency, Cincinnati, OH, May 1979.

3. R. Bohn, Evaluation Of Open Dust Sources In The Vicinity Of Buffalo, New York, EPA Contract No. 68-02-2545, Midwest Research Institute, Kansas City, MO, March, 1979.

4. T. Cuscino, Jr., et al., Iron And Steel Plant Open Source Fugitive Emission Control Evaluation, EPA-600/2-83-110, U. S. Environmental Protection Agency, Cincinnati, OH, October 1983.

5. J. Patrick Reider, Size Specific Particulate Emission Factors For Uncontrolled Industrial And Rural Roads, EPA Contract No. 68-02-3158, Midwest Research Institute, Kansas City, MO, September 1983.

6. C. Cowherd, Jr., and P. Englehart, Size Specific Particulate Emission Factors For Industrial And Rural Roads, EPA-600/7-85-038, U. S. Environmental Protection Agency, Cincinnati, OH, September 1985.

11.2.7 INDUSTRIAL WIND EROSION

11.2.7.1 General[1-3]

Dust emissions may be generated by wind erosion of open aggregate storage piles and exposed areas within an industrial facility. These sources typically are characterized by nonhomogeneous surfaces impregnated with nonerodible elements (particles larger than approximately 1 cm in diameter). Field testing of coal piles and other exposed materials using a portable wind tunnel has shown that (a) threshold wind speeds exceed 5 m/s (11 mph) at 15 cm above the surface or 10 m/s (22 mph) at 7 m above the surface, and (b) particulate emission rates tend to decay rapidly (half life of a few minutes) during an erosion event. In other words, these aggregate material surfaces are characterized by finite availability of erodible material (mass/area) referred to as the erosion potential. Any natural crusting of the surface binds the erodible material, thereby reducing the erosion potential.

11.2.7.2 Emissions And Correction Parameters

If typical values for threshold wind speed at 15 cm are corrected to typical wind sensor height (7-10 m), the resulting values exceed the upper extremes of hourly mean wind speeds observed in most areas of the country. In other words, mean atmospheric wind speeds are not sufficient to sustain wind erosion from flat surfaces of the type tested. However, wind gusts may quickly deplete a substantial portion of the erosion potential. Because erosion potential has been found to increase rapidly with increasing wind speed, estimated emissions should be related to the gusts of highest magnitude.

The routinely measured meteorological variable which best reflects the magnitude of wind gusts is the fastest mile. This quantity represents the wind speed corresponding to the whole mile of wind movement which has passed by the 1 mile contact anemometer in the least amount of time. Daily measurements of the fastest mile are presented in the monthly Local Climatological Data (LCD) summaries. The duration of the fastest mile, typically about 2 min (for a fastest mile of 30 mph), matches well with the half life of the erosion process, which ranges between 1 and 4 min. It should be noted, however, that peak winds can significantly exceed the daily fastest mile.

The wind speed profile in the surface boundary layer is found to follow a logarithmic distribution:

$$u(z) = \frac{u^*}{0.4} \ln \frac{z}{z_o} \quad (z > z_o) \qquad (1)$$

where u = wind speed, cm/sec
u* = friction velocity, cm/sec
z = height above test surface, cm
zo = roughness height, cm
0.4 = von Karman's constant, dimensionless

The friction velocity (u*) is a measure of wind shear stress on the erodible surface, as determined from the slope of the logarithmic velocity profile. The roughness height (z_o) is a measure of the roughness of the exposed surface as determined from the y intercept of the velocity profile, i.e., the height at which the wind speed is zero. These parameters are illustrated in Figure 11.2.7-1 for a roughness height of 0.1 cm.

Emissions generated by wind erosion are also dependent on the frequency of disturbance of the erodible surface because each time that a surface is disturbed, its erosion potential is restored. A disturbance is defined as an action which results in the exposure of fresh surface material. On a storage pile, this would occur whenever aggregate material is either added to or removed from the old surface. A disturbance of an exposed area may also result from the turning of surface material to a depth exceeding the size of the largest pieces of material present.

11.2.7.3 Predictive Emission Factor Equation[4]

The emission factor for wind generated particulate emissions from mixtures of erodible and nonerodible surface material subject to disturbance may be expressed in units of g/m^2-yr as follows:

$$\text{Emission factor} = k \sum_{i=1}^{N} P_i \qquad (2)$$

where k = particle size multiplier
N = number of disturbances per year
Pi = erosion potential corresponding to the observed (or probable) fastest mile of wind for the ith period between disturbances, g/m^2

The particle size multiplier (k) for Equation 2 varies with aerodynamic particle size, as follows:

AERODYNAMIC PARTICLE SIZE MULTIPLIERS FOR EQUATION 2

<30 um	<15 um	<10 um	<2.5 um
1.0	0.6	0.5	0.2

This distribution of particle size within the <30um fraction is comparable to the distributions reported for other fugitive dust sources where wind speed is a factor. This is illustrated, for example, in the distributions for batch and continuous drop operations encompassing a number of test aggregate materials (see Section 11.2.3).

In calculating emission factors, each area of an erodible surface that is subject to a different frequency of disturbance should be treated separately. For a surface disturbed daily, N = 365/yr, and for a surface disturbance once every 6 months, N = 2/yr.

Equations 2 and 3 apply only to dry, exposed materials with limited erosion potential. The resulting calculation is valid only for a time period as long or longer than the period between disturbances. Calculated emissions represent intermittent events and should not be input directly into dispersion models that assume steady state emission rates.

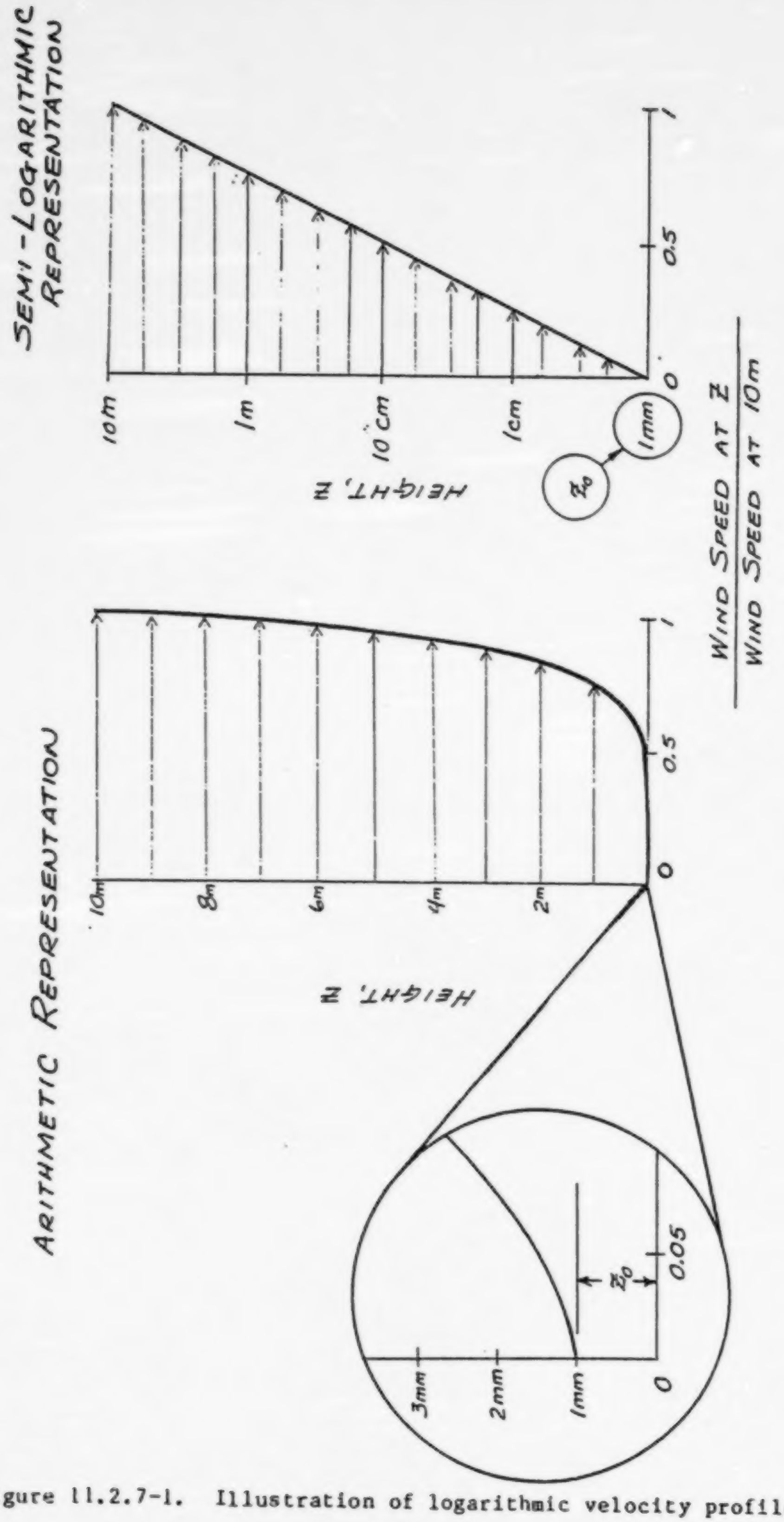


Figure 11.2.7-1. Illustration of logarithmic velocity profile.

The erosion potential function for a dry, exposed surface is:

$$P = 58\ (u^* - u^*_t)2\ 25\ (u^* - u^*_t) \qquad (3)$$

$$P = 0 \text{ for } u^* \leq u^*_t$$

where u^* = friction velocity (m/s)
u_t = threshold friction velocity (m/s)

Because of the nonlinear form of the erosion potential function, each erosion event must be treated separately.

For uncrusted surfaces, the threshold friction velocity is best estimated from the dry aggregate structure of the soil. A simple hand sieving test of surface soil (adapted from a laboratory procedure published by W. S. Chepil) can be used to determine the mode of the surface aggregate size distribution by inspection of relative sieve catch amounts, following the procedure described below. Alternatively, the threshold friction velocity for erosion can be determined from the mode of the aggregate size distribution, as described by Gillette.[5-6]

Threshold friction velocities for several surface types have been determined by field measurements with a portable wind tunnel. These values are presented in Table 11.2.7-1.

TABLE 11.2.7-1. FIELD PROCEDURE FOR DETERMINTION OF THRESHOLD FRICTION VELOCITY

Tyler sieve no.	Opening (mm)	Midpoint (mm)	u^*_t (cm/sec)
5	4		
		3	100
9	2		
		1.5	72
16	1		
		0.75	58
32	0.5		
		0.375	43
60	0.25		

FIELD PROCEDURE FOR DETERMINATION OF THRESHOLD FRICTION VELOCITY
(from a 1952 laboratory procedure published by W. S. Chepil)

1. Prepare a nest of sieves with the following openings: 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm. Place a collector pan below th crhhrj·ftaga *5M36 jj¶M

2. Collect a sample representing the surface layer of loose particles (approximately 1 cm in depth, for an encrusted surface), removing any rocks

larger than about 1 cm in average physical diameter. The area to be sampled should be not less than 30 cm.

3. Pour the sample into the top sieve (4 mm opening), and place a lid on the top.

4. Move the covered sieve/pan unit by hand, using a broad circular arm motion in the horizontal plane. Complete 20 circular movements at a speed just necessary to achieve some relative horizontal motion between the sieve and the particles.

5. Inspect the relative quantities of catch within each sieve, and determine where the mode in the aggregate size distribution lies, i. e., between the opening size of the sieve with the largest catch and the opening size of the next largest sieve.

6. Determine the threshold friction velocity from Figure 1.

The fastest mile of wind for the periods between disturbances may be obtained from the monthly LCD summaries for the nearest reporting weather station that is representative of the site in question.[7] These summaries report actual fastest mile values for each day of a given month. Because the erosion potential is a highly nonlinear function of the fastest mile, mean values of the fastest mile are inappropriate. The anemometer heights of reporting weather stations are found in Reference 8, and should be corrected to a 10 m reference height using Equation 1.

TABLE 11.2.7-2. THRESHOLD FRICTION VELOCITIES

Material	Threshold friction velocity (m/s)	Roughness height (cm)	Threshold wind velocity at 10 m (m/s)		Ref.
			z_o = Actual	z_o = 0.5 cm	
Overburden[a]	1.02	0.3	21	19	2
Scoria (roadbed material)[a]	1.33	0.3	27	25	2
Ground coal[a] (surrounding coal pile)	0.55	0.01	16	10	2
Uncrusted coal pilea	1.12	0.3	23	21	2
Scraper tracks on coal pile[a,b]	0.62	0.06	15	12	2
Fine coal dust on concrete pad[c]	0.54	0.2	11	10	3

[a] Western surface coal mine.
[b] Lightly crusted.
[c] Eastern power plant.

To convert the fastest mile of wind (u^+) from a reference anemometer height of 10 m to the equivalent friction velocity (u^*), the logarithmic wind speed profile may be used to yield the following equation:

$$u^* = 0.053\, u^+_{10} \qquad (4)$$

where u^* = friction velocity (m/s)

u^+_{10} = fastest mile of reference anemometer for period between disturbances (m/s)

This assumes a typical roughness height of 0.5 cm for open terrain. Equation 4 is restricted to large relatively flat piles or exposed areas with little penetration into the surface wind layer.

If the pile significantly penetrates the surface wind layer (i.e., with a height-to-base ratio exceeding 0.2), it is necessary to divide the pile area into subareas representing different degrees of exposure to wind. The results of physical modeling show that the frontal face of an elevated pile is exposed to wind speeds of the same order as the approach wind speed at the top of the pile.

For two representative pile shapes (conical and oval with flattop, 37 degree side slope), the ratios of surface wind speed (u_s) to approach wind speed (u_r) have been derived from wind tunnel studies.[9] The results are shown in Figure 11.2.7-2 corresponding to an actual pile height of 11 m, a reference (upwind) anemometer height of 10 m, and a pile surface roughness height (z_0) of 0.5 cm. The measured surface winds correspond to a height of 25 cm above the surface. The area fraction within each contour pair is specified in Table 11.2.7-3.

The profiles of u_s/u_r in Figure 11.2.7-2 can be used to estimate the surface friction velocity distribution around similarly shaped piles, using the following procedure:

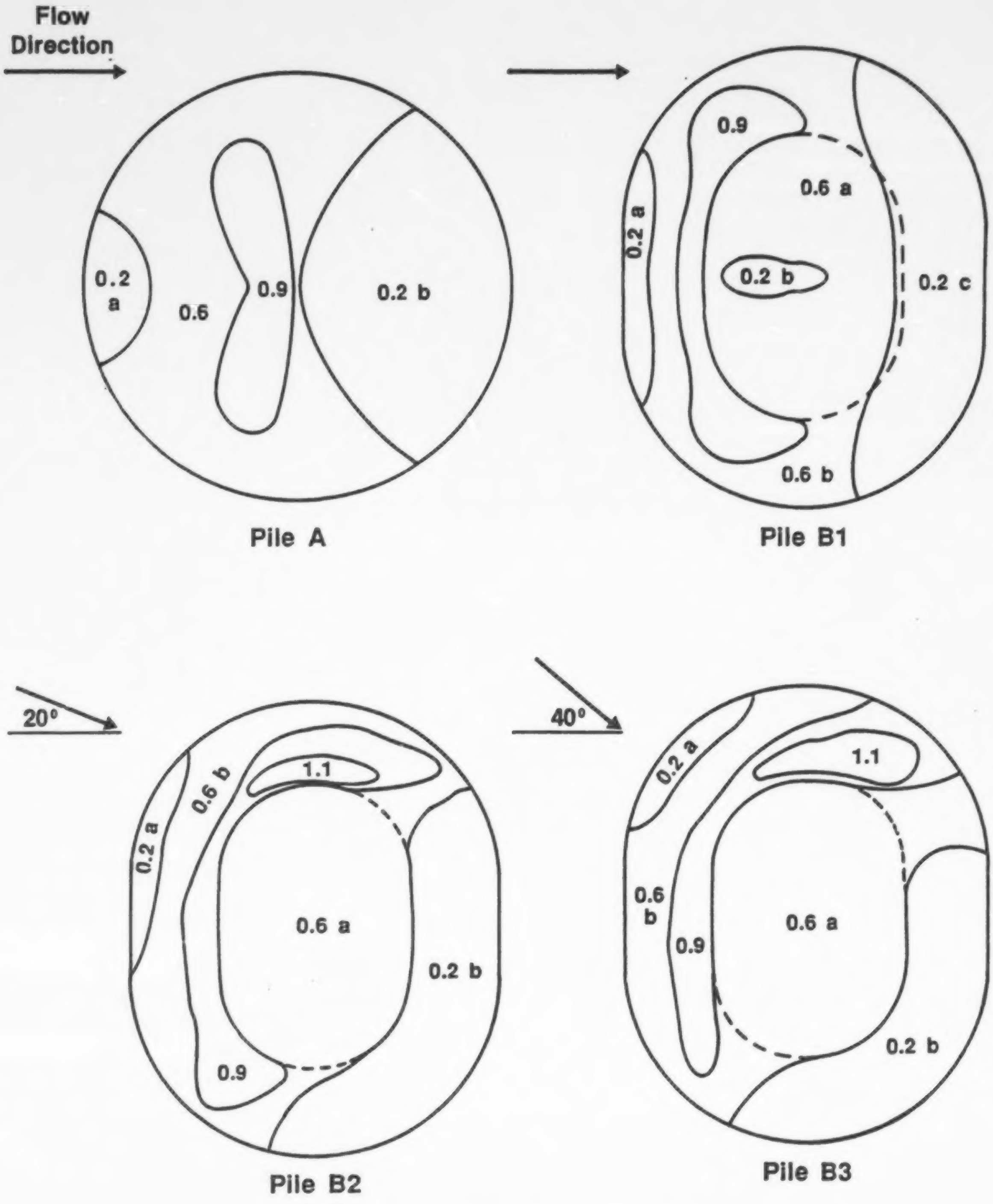
1. Correct the fastest mile value (u^+) for the period of interest from the anemometer height (z) to a reference height of 10 m (u^+_{10}) using a variation of Equation 1:

$$u^+_{10} = u^+ \frac{\ln\ (10/0.005)}{\ln\ (z/0.005)} \qquad (5)$$

   where a typical roughness height of 0.5 cm (0.005 m) has been assumed. If a site specific roughness height is available, it should be used.

2. Use the appropriate part of Figure 11.2.7-2 based on the pile shape and orientation to the fastest mile of wind, to obtain the corresponding surface wind speed distribution (u^+_s):

$$u^+_s = \left(\frac{u_s}{u_r}\right) u^+_{10} \qquad (6)$$


Flow Direction
0.2 a
0.6
0.9
0.2 b
0.9
0.6 a
0.2 a
0.2 b
0.2 c
0.6 b
20°
0.2 a
0.6 b
1.1
0.6 a
0.2 b
0.9
40°
0.2 a
1.1
0.6 b
0.9
0.6 a
0.2 b

Pile A

Pile B1

Pile B2

Pile B3

Figure 11.2.7-2. Contours of Normalized Surface Wind Speeds, u_s/u_r

3. For any subarea of the pile surface having a narrow range of surface wind speed, use a variation of Equation 1 to calculate the equivalent friction velocity (u^*):

$$u^* = \frac{0.4\ u^+_s}{\ln \frac{25}{0.5}} = 0.10\ u^+_s$$

From this point on, the procedure is identical to that used for a flat pile, as described above.

Implementation of the above procedure is carried out in the following steps:

1. Determine threshold friction velocity for erodible material of interest (see Table 11.2.7-2 or determine from mode of aggregate size distribution).

2. Divide the exposed surface area into subareas of constant frequency of disturbance (N).

TABLE 11.2.7-3 SUBAREA DISTRIBUTION FOR REGIMES OF u_s/u_r

	Percent of pile surface area (Figure 11.2.7-2)			
Pile subarea	Pile A	Pile B1	Pile B2	Pile B3
0.2a	5	5	3	3
0.2b	35	2	28	25
0.2c	-	29	-	-
0.6a	48	26	29	28
0.6b	-	24	22	26
0.9	12	14	15	14
1.1	-	-	3	4

3. Tabulate fastest mile values (u^+) for each frequency of disturbance and correct them to 10 m (u^+_{10}) using Equation 5.

4. Convert fastest mile values (u^+_{10}) to equivalent friction velocities (u^*), taking into account (a) the uniform wind exposure of nonelevated surfaces, using Equation 4, or (b) the nonuniform wind exposure of elevated surfaces (piles), using Equations 6 and 7.

5. For elevated surfaces (piles), subdivide areas of constant N into subareas of constant u^* (i.e., within the isopleth values of u_s/u_r in Figure 11.2.7-2 and Table 11.2.7-3) and determine the size of each subarea.

6. Treating each subarea (of constant N and u^*) as a separate source, calculate the erosion potential (P_i) for each period between disturbances using Equation 3 and the emission factor using Equation 2.

7. Multiply the resulting emission factor for each subarea by the size of the subarea, and add the emission contributions of all subareas. Note that the highest 24-hr emissions would be expected to occur on the windiest day of the year. Maximum emissions are calculated assuming a single event with the highest fastest mile value for the annual period.

The recommended emission factor equation presented above assumes that all of the erosion potential corresponding to the fastest mile of wind is lost during the period between disturbances. Because the fastest mile event typically lasts only about 2 min, which corresponds roughly to the halflife for the decay of actual erosion potential, it could be argued that the emission factor overestimates particulate emissions. However, there are other aspects of the wind erosion process which offset this apparent conservatism:

1. The fastest mile event contains peak winds which substantially exceed the mean value for the event.

2. Whenever the fastest mile event occurs, there are usually a number of periods of slightly lower mean wind speed which contain peak gusts of the same order as the fastest mile wind speed.

Of greater concern is the likelihood of overprediction of wind erosion emissions in the case of surfaces disturbed infrequently in comparison to the rate of crust formation.

11.2.7.4 Example calculation for wind erosion emissions from conically shaped coal pile

A coal burning facility maintains a conically shaped surge pile 11 m in height and 29.2 m in base diameter, containing about 2000 Mg of coal, with a bulk density of 800 kg/m^3 (50 lb/ft^3). The total exposed surface area of the pile is calculated as follows:

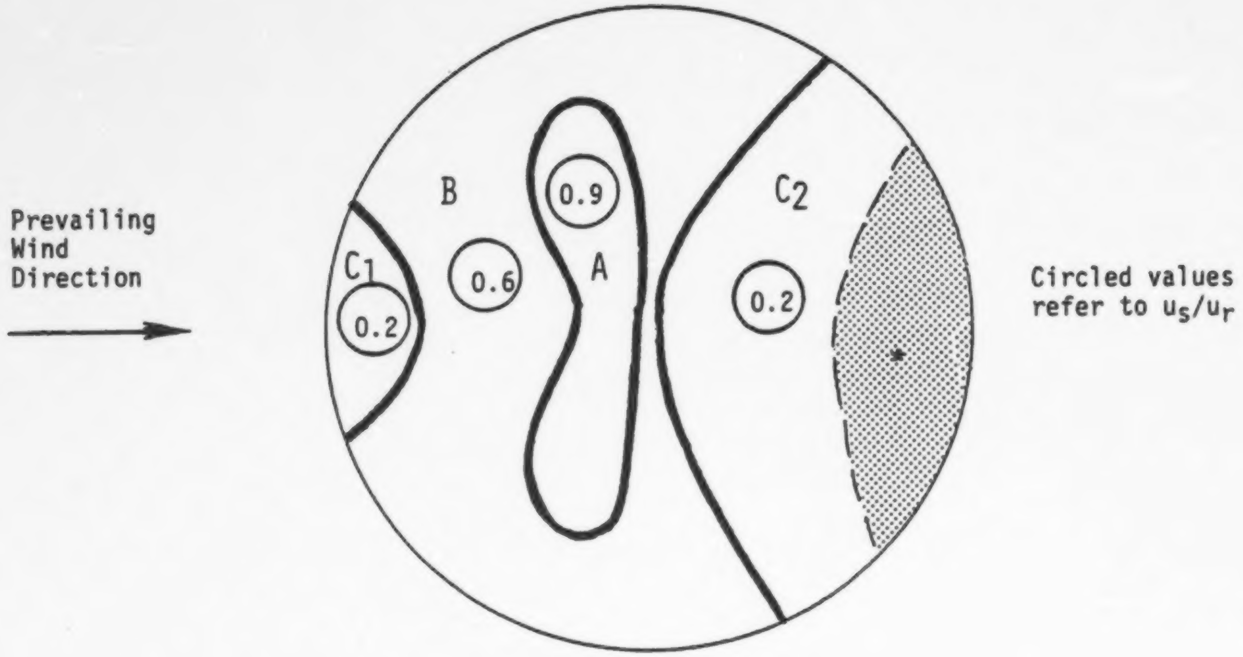
$$S = \quad r \quad r^2 + h^2$$

$$= 3.14(14.6) \quad (14.6)^2 + (11.0)^2$$

$$= 838 \ m^2$$

Coal is added to the pile by means of a fixed stacker and reclaimed by front-end loaders operating at the base of the pile on the downwind side. In addition, every 3 days 250 Mg (12.5% of the stored capacity of coal) is added back to the pile by a topping off operation, thereby restoring the full capacity of the pile. It is assumed that (a) the reclaiming operation disturbs only a limited portion of the surface area where the daily activity is occurring, such that the remainder of the pile surface remains intact, and (b) the topping off operation creates a fresh surface on the entire pile while restoring its original shape in the area depleted by daily reclaiming activity.

Because of the high frequency of disturbance of the pile, a large number of calculations must be made to determine each contribution to the total annual wind erosion emissions. This illustration will use a single month as an example.


B
0.9
C$_2$
Prevailing Wind Direction
C$_1$
0.6
A
0.2
0.2
Circled values refer to u_s/u_r
*

* A portion of C_2 is disturbed daily by reclaiming activities.

Area ID	$\frac{u_s}{u_r}$	Pile Surface	
		%	Area (m^2)
A	0.9	12	101
B	0.6	48	402
$C_1 + C_2$	0.2	40	335
			838

Figure 11.2.7-3. Example 1: Pile surface areas within each wind speed regime.

Step 1: In the absence of field data for estimating the threshold friction velocity, a value of 1.12 m/s is obtained from Table 11.2.7-2.

Step 2: Except for a small area near the base of the pile (see Figure 11.2.7-3), the entire pile surface is disturbed every 3 days, corresponding to a value of N = 120/yr. It will be shown that the contribution of the area where daily activity occurs is negligible so that it does not need to be treated separately in the calculations.

Step 3: The calculation procedure involves determination of the fastest mile for each period of disturbance. Figure 11.2.7-4 shows a representative set of values (for a 1 month period) that are assumed to be applicable to the geographic area of the pile location. The values have been separated into 3 day periods, and the highest value in each period is indicated. In this example, the anemometer height is 7 m, so that a height correction to 10 m is needed for the fastest mile values. From Equation 5,

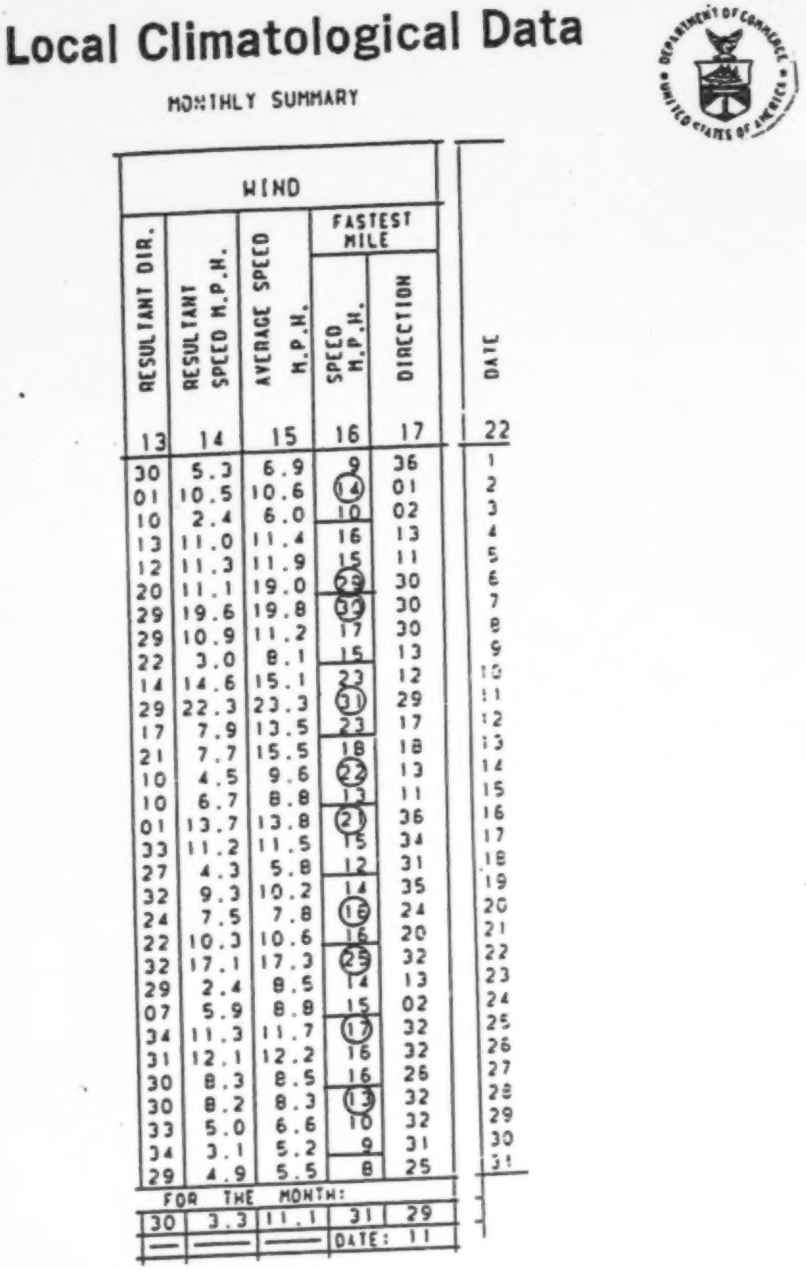
$$u^+_{10} = u^+_7 \frac{\ln (10/0.005)}{\ln (7.0.005)}$$

$$u^+_{10} = 1.05\ u^+_7$$

Step 4: The next step is to convert the fastest mile value for each 3 day period into the equivalent friction velocities for each surface wind regime (i. e., u_s/u_r ratio) of the pile, using Equations 6 and 7. Figure 11.2.7-3 shows the surface wind speed pattern (expressed as a fraction of the approach wind speed at a height of 10 m). The surface areas lying within each wind speed regime are tabulated below the figure.

The calculated friction velocities are presented in Table 11.2.7-4. As indicated, only three of the periods contain a friction velocity which exceeds the threshold value of 1.12 m/s for an uncrusted coal pile. These three values all occur within the $u_s/u_r = 0.9$ regime of the pile surface.

Step 5: This step is not necessary because there is only one frequency of disturbance used in the calculations. It is clear that the small area of daily disturbance (which lies entirely within the $u_s/u_r = 0.2$ regime) is never subject to wind speeds exceeding the threshold value.



Local Climatological Data

DEPARTMENT OF COMMERCE • UNITED STATES OF AMERICA

MONTHLY SUMMARY

WIND					
RESULTANT DIR.	RESULTANT SPEED M.P.H.	AVERAGE SPEED M.P.H.	FASTEST MILE		DATE
			SPEED M.P.H.	DIRECTION	
13	14	15	16	17	22
30	5.3	6.9	9	36	1
01	10.5	10.6	⑭	01	2
10	2.4	6.0	10	02	3
13	11.0	11.4	16	13	4
12	11.3	11.9	15	11	5
20	11.1	19.0	㉓	30	6
29	19.6	19.8	㉝	30	7
29	10.9	11.2	17	30	8
22	3.0	8.1	15	13	9
14	14.6	15.1	23	12	10
29	22.3	23.3	㉛	29	11
17	7.9	13.5	23	17	12
21	7.7	15.5	18	18	13
10	4.5	9.6	㉒	13	14
10	6.7	8.8	13	11	15
01	13.7	13.8	㉑	36	16
33	11.2	11.5	15	34	17
27	4.3	5.8	12	31	18
32	9.3	10.2	14	35	19
24	7.5	7.8	⑯	24	20
22	10.3	10.6	16	20	21
32	17.1	17.3	㉕	32	22
29	2.4	8.5	14	13	23
07	5.9	8.8	15	02	24
34	11.3	11.7	⑰	32	25
31	12.1	12.2	16	32	26
30	8.3	8.5	16	26	27
30	8.2	8.3	⑬	32	28
33	5.0	6.6	10	32	29
34	3.1	5.2	9	31	30
29	4.9	5.5	8	25	31
FOR THE MONTH:					
30	3.3	11.1	31	29	
—	—	—	DATE: 11		

Figure 11.2.7-4. Daily fastest miles of wind for periods of interest.

TABLE 11.2.7-4. EXAMPLE 1: CALCULATION OF FRICTION VELOCITIES

3 Day period	u^{+}_{7}		u^{+}_{10}			$u^{*} = 0.1\ u^{+}_{s}$ (m/s)		
	(mph)	(m/s)	(mph)	(m/s)	u_s/u_r	0.2	0.6	0.9
1	14	6.3	15	6.6		0.13	0.40	0.59
2	29	13.0	31	13.7		0.27	0.82	1.23
3	30	13.4	32	14.1		0.28	0.84	1.27
4	31	13.9	33	14.6		0.29	0.88	1.31
5	22	9.8	23	10.3		0.21	0.62	0.93
6	21	9.4	22	9.9		0.20	0.59	0.89
7	16	7.2	17	7.6		0.15	0.46	0.68
8	25	11.2	26	11.8		0.24	0.71	1.06
9	17	7.6	18	8.0		0.16	0.48	0.72
10	13	5.8	14	6.1		0.12	0.37	0.55

Steps 6 and 7: The final set of calculations (shown in Table 11.2.7-5) involves the tabulation and summation of emissions for each disturbance period and for the affected subarea. The erosion potential (P) is calculated from Equation 3.

TABLE 11.2.7-5. EXAMPLE 1: CALCULATION OF PM_{10} EMISSIONS[a]

3 Day period	u^{*} (m/s)	$u^{*} - u^{*t}$ (m/s)	P (g/m^2)	ID	Pile Surface Area (m^2)	kPA (g)
2	1.23	0.11	3.45	A	101	170
3	1.27	0.15	5.06	A	101	260
4	1.31	0.19	6.84	A	101	350
					Total PM_{10} emissions =	780

[a] where u^{*}_{t} = 1.12 m/s for uncrusted coal and k = 0.5 for PM_{10}.

For example, the calculation for the second 3 day period is:

$$P_2 = 58(1.23 - 1.12)_2 + 25(1.23 - 1.12)$$

$$= 0.70 + 2.75 = 3.45\ g/m^2$$

The PM_{10} emissions generated by each event are found as the product of the PM_{10} multiplier (k = 0.5), the erosion potential (P), and the affected area of the pile (A).

As shown in Table 11.2.7-5, the results of these calculations indicate a monthly PM_{10} emission total of 780 g.

11.2.7.5 Example calculation for wind erosion from flat area covered with coal dust

A flat circular area of 29.2 m in diameter is covered with coal dust left over from the total reclaiming of a conical coal pile described in the example above. The total exposed surface area is calculated as follows:

$$S = \frac{}{4} d^2 = 0.785\ (29.2)^2 = 670\ m^2$$

This area will remain exposed for a period of 1 month when a new pile will be formed.

Step 1: In the absence of field data for estimating the threshold friction velocity, a value of 0.54 m/s is obtained from Table 11.2.7-2.

Step 2: The entire surface area is exposed for a period of 1 month after removal of a pile and N = 1/yr.

Step 3: From Figure 11.2.7-5, the highest value of fastest mile for the 30 day period (31 mph) occurs on the 11th day of the period. In this example, the reference anemometer height is 7 m, so that a height correction is needed for the fastest mile value. From Step 3 of the previous example, $u^+_{10} = 1.05\ u^+_7$, so that $u^+_{10} = 33$ mph.

Step 4: Equation 4 is used to convert the fastest mile value of 33 mph (14.6 m/s) to an equivalent friction velocity of 0.77 m/s. This value exceeds the threshold friction velocity from Step 1 so that erosion does occur.

Step 5: This step is not necessary because there is only one frequency of disturbance for the entire source area.

Steps 6 and 7: The PM_{10} emissions generated by the erosion event are calculated as the product of the PM_{10} multiplier (k = 0.5), the erosion potential (P) and the source area (A). The erosion potential is calculated from Equation 3 as follows:

$$\begin{aligned} P &= 58(0.77 - 0.54)2 + 25(0.77 - 0.54) \\ &= 3.07 + 5.75 \\ &= 8.82\ g/m^2 \end{aligned}$$

Thus the PM_{10} emissions for the 1 month period are found to be:

$$\begin{aligned} E &= (0.5)(8.82\ g/m^2)(670\ m^2) \\ &= 3.0\ kg \end{aligned}$$

References for Section 11.2.7

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